U. S. ARMY TEST AND EVALUATION COMMAND
BACKGROUND DOCUMENT

AMSTE-RP-702-100
Test Operations Procedure 1-1-008 31 March 1972

TROPIC ENVIRONMENTAL CONSIDERATIONS

SECTION I
GENERAL

1. Purpose and Scope. This document describes tropic environmental considerations, damaging factors and elements, and degradation of materials. This document also treats sound, visibility and human factors engineering evaluations in the tropic. It does not consider simulated testing of equipment and materials in environmental chambers.

2. Basic Information.

a. Tropic environment and its effects are complex and difficult to simulate or create in chambers. Characteristics of this tropic environment are described in section II. Degrading factors and elements, effects on materiel and materials, sound and visibility, and human factors engineering evaluations are also treated in section II.

b. Increased emphasis is being placed on tropic testing because of high equipment failures in tropic areas during military operations. The tropic testing of materials, started in the late 1930's, was limited primarily to investigations of corrosion and methods of corrosion control. At the outset of World War II it was realized that tropic testing was more significant because of climatic, insect and animal damage. The importance of this type of testing culminated in the early 1950's with the selection of the Canal Zone as the tropic test site. The United States Army Research and Development Office,

Panama, was established in 1962. Under the new organization of the Army Materiel Command and Headquarters, U. S. Army Test and Evaluation Command, the name of the test site was changed to the United States Army Tropic Test Center.

c. The Canal Zone bisects the Isthmus of Panama at approximately 9 degrees north latitude. It is approximately 55 miles long and 10 miles wide.(appendix B-1) Within this relatively small area, there exists a marked difference in the environments of the Atlantic side and the Pacific side. Major differences include amounts of rainfall and vegetation. Two seasons prevail in the Zone, the wet season is about 8 months long and the dry season about 4 months long.

(1) Atlantic Side. From approximately the center of the Zone northwest to the Atlantic Ocean, average annual precipitation generally exceeds 95 inches. Even during the "dry" season, this area averages an inch or more of rain per month. Daily temperatures range from about 85°F. during the afternoon to about 75°F. in the early morning hours. Relative humidity is high, reaching 95 to 100 percent for several hours nearly every night. Relatively dense forests are widespread throughout the area. Trees are predominantly broadleaf evergreen species with some broadleaf evergreen species and some broadleaf deciduous species. The top of the forest canopy ranges from 90 to 125 feet.

(2) Pacific Side. From approximately the center of the Zone, southeast to the Pacific Ocean, precipitation decreases from its maximum to less than 70 inches per year at the coast. Normally less than one-inch of rain per month falls during the two driest months. Daily temperatures are higher than on the Atlantic side, reaching into the 90's during the afternoons with early morning temperatures dropping below 70°F. on some occasions. Relative humidity is fairly high, reaching 100 percent nearly every night, but somewhat lower during the dry season. Broadleaf forests are widespread with a larger percent of deciduous trees than on the Atlantic side. Tree growth is less dense causing more dense tangle and undergrowth. The top of the forest canopy ranges from 60 to 110 feet.

d. All materials undergo changes with time. The rate at which the change takes place and the result of the changes have a definite bearing upon the use and life expectancy of any material or item of equipment. The Army recognizes that the degradation, or failure process, varies widely due to geographical location, and therefore, maintains three environmental test centers: Arctic, Desert, and Tropic. Each of these centers has widely different climatic conditions which result in different effects upon materiel as well as different degradation processes. Basically it is the combination of warm temperature and high relative humidity that makes the Tropic Test Center unique. This combination results in other distinctive features such as heavy

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13. ABSTRACT

Provides background information on the test of materials in a tropic environment. Discusses tropic environmental characteristics, climate, damaging factors and elements, properties of materials, protection and degradation of materials, human factors, and sound and visibility in the jungle. Applicable to test in the Canal Zone, Isthmus of Panama. Not applicable to laboratory testing.

Details of illustrations in this document may be better studied on microfiche

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vegetative growth, and the preponderance of large numbers and varieties of microorganisms, insects, and animals. All of these may contribute to degradation and/or failure of materials. The variations of the environment within the Canal Zone are discussed elsewhere, however, it is important to recognize these variations when determining specific test locations or evaluating results. Actually, few of the environmental features can be simulated under repeatable, controlled conditions in environmental chambers. One of the main differences between chamber testing and the type of environmental testing done at this Center is the exposing of equipment or material to a multitude of variables simultaneously, and to many influences not perfected in chambers to include animal and plant life. In this way USATTC is able to observe results form the interaction of the contributing phenomena. Someday, if all of the contributing phenomena are fully understood, it may be possible to simulate accurately the typical environmental degradation process in the laboratory, and even to accelerate it. Until that distant time, the natural phenomena and normal degradation rates must be relied on to evaluate the environmental degradation process.

SECTION II
TECHNICAL PRESENTATION

3. Tropic Environmental Characteristics.

a. Topography, soil type, and vegetative cover are of primary importance in the success or failure of mobility tests, personnel movement (combat activity), propagation of electromagnetic energy, airdrops, target acquisition, and those tests involving line of sight or aerial visibility. The primary sources of terrain data topography are topographic maps and vertical aerial photographs. Figure 1 presents a generalized exhibit of the topographic slopes prevailing in the Canal Zone. The classification limits are arbitrary. Within the boundaries indicated, the predominant slopes are shown. This does not mean that other slopes do not exist within the unit, but it does indicate that the slopes shown are of such frequent occurrence that they characterize the area as a whole. Figure 1 may be used to locate areas in which topographic configurations are significant to the test activity. More detailed and precise information may be obtained from graphic maps, aerial photographs, or reference - "Canal Zone Mobility Test Areas and Terrain Measurements" (appendix A).

b. Soil is a significant physical characteristic to many activities as well as to materiel undergoing test. Primary importance to activities may lie in the soil strength characteristics, that is, its capability to provide support for structures, traction for vehicles, support for personnel on foot, etc. The influence of soil on materiel undergoing test may depend on its chemical properties, grain-size distribution, electrical conductivity, ease of excavating and packing, ability to transmit seismic or shock waves, and its

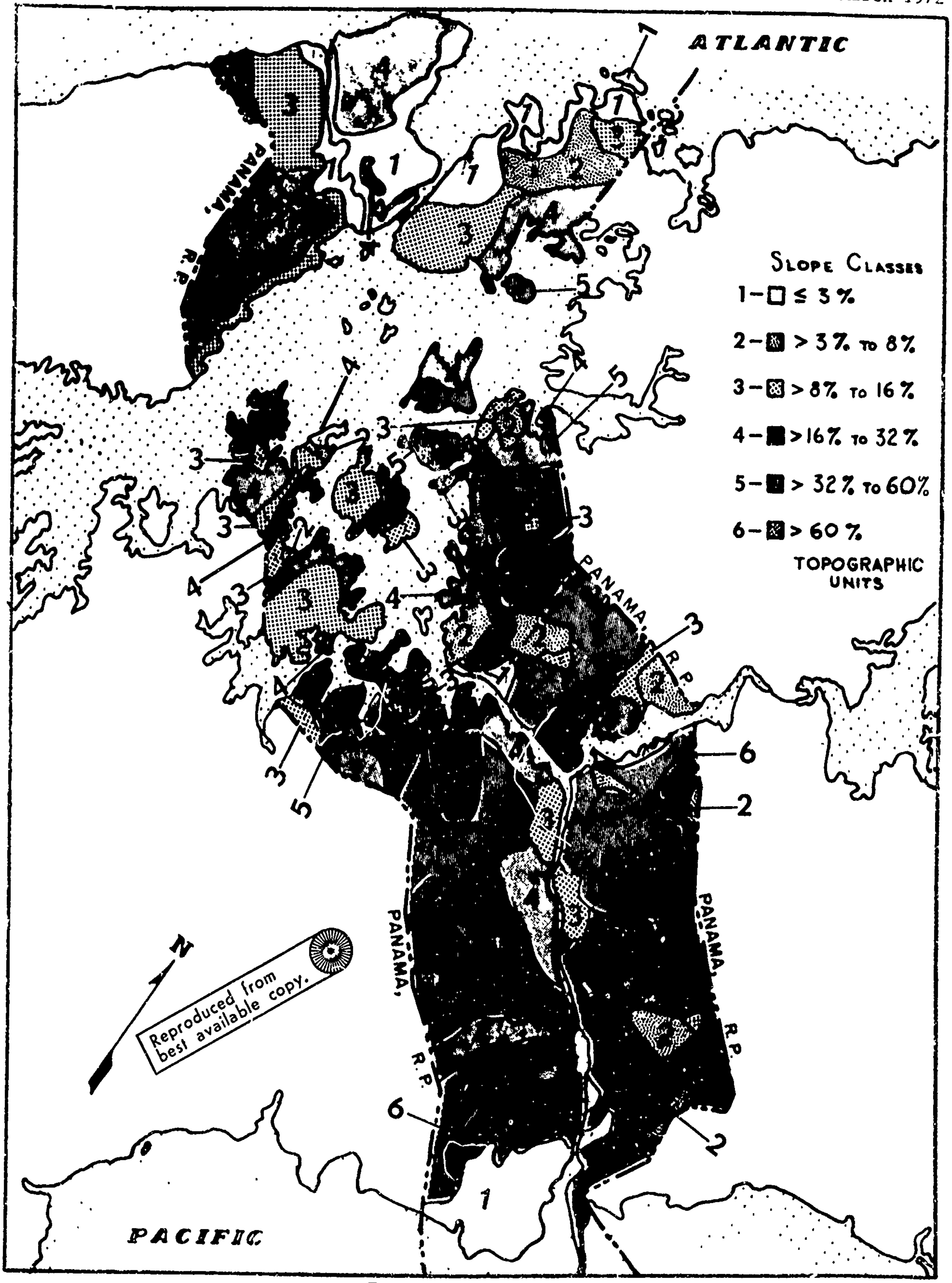

Figure 1 Slope Classes.

moisture content. All of these characteristics, to a varying extent, are related to or modified by the tropic climate. The constant warmth (but not extreme heat), abundant moisture, and easily weatherable parent material and minerals foster a production of uniformity in the soils. Tropic soils therefore do not exhibit the diversity of physical characteristics found in other climatic areas of the world. Nevertheless, significant variations do occur and frequently within short distances. Even though the soils of the Canal Zone have developed in a tropic climate, laterites are not found. Most soils in the Canal Zone are deep and fine-textured throughout the profile. Areas of shallow, fine-textured soils do occur, as well as areas of deep, moderately fine and medium-textured soils. Alluvial soils are found adjacent to the larger streams and slack water areas near the oceans. The soils map, figure 2, is a generalized extraction from USDA Technical Bulletin No. 94. The soils within areas may vary in physical strength characteristics. Factors affecting mobility, such as slipperiness, plasticity, and strength, change rapidly with time and may vary significantly over a short distance. These factors are related to the amount of soil moisture, season of the year, and terrain slope. The pronounced seasons (wet and dry), variation in rainfall, and topography make it impractical to predict average soil strength for a specific area with any degree of accuracy. These determinations must be made just prior to or concurrently with the materiel test. Soil strengths are generally higher during the dry season, therefore, if soft soils are desired in the dry season, flat lowlands or poorly drained areas must be selected for testing.

c. Vegetation and lush plant growth are predominant in the Canal Zone. There are 28 recognizable different plant types (associations) that can develop in the tropics. When vegetation has an influence on the outcome of testing, as it often does, a description of the vegetation and the vegetative interface should be prepared. This will assist in assuring that follow-on tests are conducted on sites which are botanically similar to the original site. It will also permit correlations to be made between performance of the test item in the Canal Zone with other parts of the world where similar plant associations exist. When vegetation can influence test results, consideration should be given to selecting those test sites that have representative vegetation types found in other tropic regions where the materiel might be employed. Some of the tests that are very sensitive to vegetative influences and therefore require detailed vegetation descriptions are: (1) dropping of men and test items through jungle canopy; (2) movement of personnel and vehicles through vegetation; (3) radio and radar propagation through intervening vegetation; (4) restricted fields of fire; (5) dispersion of aerosols and smokes; (6) and detonation of ordnance items.

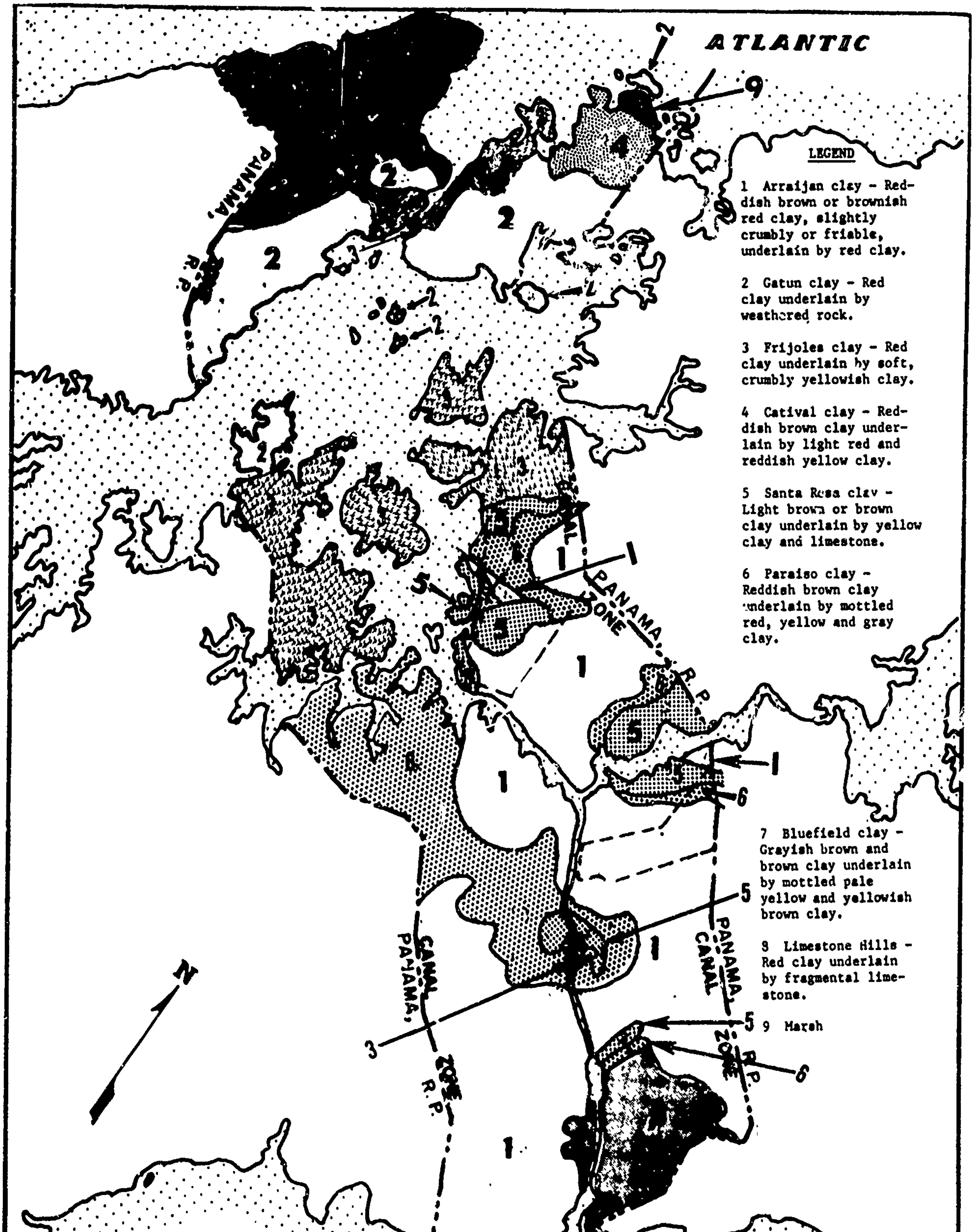

Figure 2 Soil Classes

d. Area physical characteristics descriptions included six major areas. (appendix B-2)

(1) Fort Sherman. There are four major types of terrain: (1) undulating uplands; (2) drained lowlands; (3) undrained lowlands; and (4) Coastal fringe

(a) The undulating uplands consist of dissected hills, 50 to 400 feet in elevation, slopes ranging from 8 to 32 percent, and many turbulent streams with fluctuating amounts of water traversing the area. Most of the soils are composed of clay throughout the profile. There are some small areas which have moderately fine-textured surface layers. The drained lowlands, below 20 feet in elevation, are systematically (artificially) ditched swamps and marshes. The soils are predominantly clay throughout the profile, but other surface textures occur in the flood plain of the Rio Chagres and in the drained areas. Medium and moderately-fine surface textures dominate in the Rio Chagres flood plain, while in the drained areas surface textures are fine to moderately fine. In the undrained lowlands, Mojinga Swamp is the largest fresh water swamp in the Canal Zone. Soil textures are generally clay or silty clay with small local areas of coarser textures occurring. Water stands over most of the area throughout the year, however, there are seasonal fluctuations both in depth and area covered. Soil strengths are always low in the swamp areas. The coastal fringe of Fort Sherman east to the Chagres River consists of short, cove-like, sandy beaches, separated by wave-cut cliffs, escarpments, and coral reefs. A continuous 1200-meter sandy beach lies southwest of the river mouth. This beach varies in width from 25 to 50 meters and is backed by an unpaved road. Wave heights along the fringe are generally less than 1 meter, except during the dry season when the height may be much higher. The diurnal tidal range averages 0.5 meter, resulting in a change in beach width of 5 to 10 meters.

(b) The high rainfall contributes to a dense forest growth with many epiphytes such as bromeliads and orchids. The vegetation of the area approximates a true tropical rain forest. The forests are not "true" rain forests because of the existence of a relatively long dry season. The canopy is irregular and not single-layered, which causes the canopy to vary from 60 to 110 feet. This allows sufficient light to penetrate in some areas, so that moderately dense undergrowth occurs. Except in these "lighted" areas the undergrowth is usually sparse. Some emergent trees reach 150 feet, although the normal canopy level ranges between 90 to 110 feet. This area has not suffered appreciably from cutting and burning so the forests are near-mature. Second-growth forests which occur in limited areas are lower but more dense and tangled. In those areas where saltwater penetrates inland, dense stands of red mangrove occur. These second growth, prop-rooted trees are of low stature and rarely reach 30 feet in height. In brackish areas the more mature white mangrove replaces the red and ranges up to 70 feet in height. A few black mangrove also are found in this area. Where low, marshy areas adjoin rising terrain, extremely dense stands of bibiscus

(mahoe) are found. There are few areas of grassland, and these are found in low, wet areas. The Mojinga fresh water swamp water depth varies from 8 to 48 inches.

(2) Coco Solo.

(a) The Coco Solo area consists of rolling hills, up to 150 feet in elevation, bordered to the seaward side by a flat saltwater marsh. The soils have a wide range of surface textures, ranging from loamy sand to clay. Moderately fine-textured surface layers are predominant. The coarser textured soils occur at the lower elevations with the finer textures occurring at higher elevations. The area is underlaid with clay. The saltwater marsh is a systematically drained area with a fringe of sandy beaches and coral reefs.

(b) The vegetation occurring in this area is extremely varied, and therefore it is impossible to characterize it in simple terms. The area is virtually an island surrounded by poorly drained saline flats which support a growth of two species, white mangrove (up to 80 feet high) and a large fern, Acrostichum spp (up to 14 feet high). This is a mature association which is maintained as long as the flats remain fairly saline. Where the flats adjoin higher ground, an abrupt transition in vegetation occurs. Between 50 and 70 different species of trees are found here. Most of these are evergreen and contained within an acre of forest. The canopy may range up to 100 feet (gallery forest); but is multi-storied and broken. Undergrowth is usually dense, with an abundance of wild pineapple and climbers. The high rainfall contributes to dense growth with numerous orchids, bromeliads, and aroids occurring. Virtually all level areas in the past have been burned and these areas are now in solid stands of mixed grasses which reach a height of 20 feet unless cut frequently. In summary, the Coco Solo area may be described as a mosaic of transitional types; it is stable only in the mangrove dominated flats.

(3) Gamboa Areas.

(a) The Gamboa areas (A-1) are made up of maturely dissected hills, the highest elevation being about 600 feet (figure 6). The areas have many steep slopes, some in excess of 60 percent. Ridges are sinuous with narrow tops and long steep sides. Streams are closely spaced with a fine network of seasonal rills draining into numerous low gradient perennial streams. The A-2 area soil is more varied than that of the A-1 area (figure 6). Approximately half of the A-2 area is composed of deep, fine textured clay. The remainder of the area has shallow, clay soils which are closely underlaid with rock at varying depths. There are numerous large rock outcrops on the side slopes. Reaction of the deep soil is strongly acid to medium acid. The A-2 area has been released by USATTC as a test area. However, it is described here because of the numerous

tests that have been conducted in the area in the past, and because it is available for future use should the requirement arise.

(b) The vegetation characteristics of both the A-1 and A-2 areas are discussed together because of their close proximity and similar rainfall. The mean annual precipitation of both areas is 90 inches, however there is a more even seasonal distribution than on the Pacific coast. There is a marked deficiency of rain during the December to May dry season. This variation in precipitation has caused the growth of a seasonal semievergreen forest. Approximately 32 percent of the canopy tree species are deciduous or semideciduous. Semideciduous species lose the majority of their leaves only in severe dry seasons, but do not in wetter "dry" seasons. A large portion of both areas has grown to a climax (mature) forest. The canopy of these forests reaches 90 feet with occasional emergents to 120 feet. The majority of tree species have small boles to 24 inches in diameter at breast height (DBH), but some giants (Cuipo, Espave, Amarillo real) reach 75 inches DBH. The canopy coverage in these areas is usually greater than 80 percent with little undergrowth. During the dry season, personnel can easily move about under the canopy along a "park like" forest floor. Sudden changes in relief, from deeply cut stream beds to sharply defined hills, are the principal deterrents to mobility, not the vegetation, but the overall aspect of the forest remains the same.

(c) Areas of thick and tangled second growth forest occur primarily along the roads or in areas that have been farmed in the recent years. Tree species are shorter (up to 75 feet in height) and more deciduous. Vines, lianas, and climbing bamboo are prevalent along with dense stands of black palm and wild pineapple. Personnel movement on existing trails which are not used regularly is restricted to the speed at which the trail can be cleared with a machete. Areas that are burned repeatedly support pure stands of Guinea grass, to 8 feet in height, or grass mixed with wild banana (<u>Heliconia spp</u>). There are several of these areas, two in excess of 20 acres.

(4) Empire Range

(a) The Empire Range is situated on the Pacific slope of the divide and on the west side of the canal (figure 6). The area consists of a dissected hilly terrain with a general summit elevation of about 600 feet. Generally, slopes are less extreme than those of the Gamboa areas. Drainage lines are widely spaced, with trunk streams being low gradient. Rock outcrops are common on the steeper side slopes. Soils are deep to shallow and most of the area is composed of deep, fine-textured soils consisting of clay throughout the profile. A portion of the area has shallow, clay soils underlaid with rock at varying depths. Reaction of both deep and shallow soils is very strongly acid to neutral. Areas of alluvium, ranging in texture from medium to fine, are found adjacent to the major streams.

(b) The location, sharply rolling terrain, previous land usage, and mean annual rainfall of 80 inches determine the aspects of the climax vegetation. The area shows evidence of having been used for pasture or farm land within the past 70 years, and as a result the forest is not at climax. The forest is a late-stage, second-growth association. Some large trees, principally Amarillo real and Palma real, are relice left from former forests that were not felled. The second-growth species have formed a broken and mixed stand, with an irregular canopy ranging from 80 to 110 feet. The irregularities in this area are so pronounced that it is difficult to describe the vegetation. Canopy coverage may vary from 40 percent to 100 percent within a small area, and undergrowth from virtually none to an impenetrable tangle. Some of this variation is caused by wind throw of large trees which are shallow rooted, especially along the ridge tops where the soil is shallow. A dense area of shrubs, vines, and creepers soon occupy any vacated area. Another cause of the variation is the difference in soil depth and moisture between the well-drained ridge tops and the poorly-drained valley floors (deep soil). It is also suspected that there are significant differences in rainfall within relatively small areas because of the effects of the sharp changes in elevation.

(c) Generalizations that can be made of this area include the fact that 60 percent of the canopy species are deciduous or semideciduous. This causes marked changes in horizontal target obscuration and visibility from the dry season to set season. Further, the majority of the forest has a well-defined subcanopy of palms at 60 to 70 feet, and numerous small palms appear in the ground cover. Eight reproducing species of palm occur frequently which indicates that they will remain an integral part of the plant association.

(5) Chiva Chiva. (appendix B-1) The Chiva Chiva area is situated on the Pacific slope of the divide and on the east side of the canal. The area contains approximately 50 acres. The topography is relatively flat with some gently rolling, low slopes. Soils are deep and fine-textured with surface layers ranging from silty clay loam to clay 6 to 10 inches deep. The reaction is slightly acid. The subsoil is dark brown to grayish brown, mottled clay. Reaction is medium to slightly acid. This area supports a solid stand of mixed grasses and sedges, principally Guinea grass, Panicum maximum, which reaches a height of 8 feet if not cut. This area is surrounded by a dense jungle.

(6) Pacific Coat Beaches. The coastal fringe on the Pacific side of the Canal Zone has a limited utility for test operations because of the high concentration of cultural development. However, several miles of coast south and west of the Canal entrance may be used in landing craft operations. The area offers one distinct advantage in that the large diurnal tide, which varies from about 12 to 20 feet, produces wide tidal flats on which the surface may be sand, mud, or rock. These coastal interfaces are analogous to many beach areas throughout the world, and they impose unique problems to materiel and personnel.

4. Climate.

a. The Canal Zone climate is generally referred to as "humid tropic." This general term encompasses two climatic categories as defined in Army Regulation 70-38 (appendix A) the wet-warm, category 1, and wet-hot, category 2. Table 1 defines categories 1 through 5. Dry season temperatures may exceed the 95°F.wet-hot limit, but the humidity rate of the dry season is higher than that encountered in the hot-dry climatic category. The selection of a specific test area within the Canal Zone is no assurance that the test item will undergo all the enviornmental rigors that can be encountered in other humid tropic areas of the world. However, studies conducted by the Department of Defense and the US Department of Agriculture show a high degree of similarity between the Canal Zone and large areas of Southeast Asia and other tropical regions.

Table 1. Climatic Categories 1 through 5 (AR 70-38)

	Operational Conditions			Storage and Transit Conditions	
Climatic Category	Ambient Air Temperature (°F)	Solar Radiation BTU/ft^2/hr (langleys/hr)	Ambient Relative Humidity (%)	Induced Air Temperature (°F)	Induced Relative Humidity (%)
1 Wet-Warm	Nearly Constant 75	Negligible	95 to 100	Nearly Constant 80	95 to 100
2 Wet-Hot	78 to 95	0 to 360 (0 to 97.64)	74 to 100	90 to 160	10 to 85
3 Humid-Hot Coastal Desert	85 to 100	0 to 360 (0 to 97.64)	63 to 90	90 to 160	10 to 85
4 Hot-Dry	90 to 125	0 to 360 (0 to 97.64)	5 to 20	90 to 160	2 to 50
5 Inter-mediate Hot-Dry	70 to 110	0 to 360 (0 to 97.64)	20 to 85	70 to 145	5 to 50

b. The Canal Zone is centered in an area where four major climatic modifiers overlap. These modifiers are the Pacific Ocean, Atlantic Ocean (Caribbean Sea), North America, and South America. The interplay of these modifers diffuses the weather pattern over the Canal Zone, thus producing more irregular changes than are generally found in other humid tropic regions. Based on this irregularity, more emphasis should be placed on the extremes rather than the average. Table 2 lists averages and extremes of several elements. Known weather hazards in the Canal Zone are flooding, wind gusts at the onset of thunderstorms, hail, and whirlwinds. While flooding is a frequent hazard (even during the dry season), the other hazards are so extremely rare and localized that they are not considered in planning. The Canal Zone has two distinct seasons, the dry and rainy (wet).

TABLE 2. Typical Weather Data, Canal Zone[a]

Element	Pacific Side Dry[b]	Pacific Side Rainy[c]	Atlantic Side Dry[b]	Atlantic Side Rainy[c]
Daytime temperature, °F.	82-90[d]	82-87[d]	80-86[d]	82-86[d]
Temperature at night and during heavy rainstorms, °F.	65-72	75-78	65-72	75-78
Relative humidity at noon on rainless days, %	48	67	67	73
Dew point, all day, °F.	71	75	76	76
Duration of sunshine, daily average, hours	8.5	5.1	8.6	5.7
Solar radiation on horizontal plane, average, daily, langley (direct)	?	?	330	100-200[e]
Sky radiation on horizontal plane, average, daily (indirect)	?	?	190	185-285[e]
Global radiation on horizontal plane, average, daily	500	350	520	385
Global radiation, monthly maximum, langleys/day	560	400	570	500
Prevailing wind direction	N	NW	NNE	NW or S
Mean wind speed, noon, mph	10-12	5-7	12-14	6-8
Mean wind speed, night, mph	6-8	3-4	12-14	3-4
Rainfall, monthly average, inches	0.5-1	9-14[f]	1.5-2	11-25[f]
Rainfall, monthly maximum, inches	7.1	31	16	45
Rainfall, 24-hour maximum, inches	4.8	5.7	9	14[g]
Rainfall, 1-hour maximum, inches	1.3	3.8	4.5	5.7
Rainfall, yearly maximum, inches	117		183	
Rainfall, yearly average, inches	80		130	
Jungle temperature day	80-85	81-83	79-81	80-83
Jungle temperature night	74	76-77	75	75
Highest temperature ever measured	102	94	103	98
Lowest temperature ever measured	63	63	63	64

[a] Sufficient measurements for this table are available only for the areas of Balboa, Fort Clayton, and Fort Sherman Coco Solo, but not for the interior.

[b] Dry season begins usually in mid-December and ends usually in mid-April. Given data apply to February and March.

[c] Data given for rainy season apply to June through November.

[d] All given values are "reasonable guesses" derived from measurements made by the Army Meteorological Team and Panama Canal Company.

[e] June, July

[f] November

[g] Madden Dam, in the middle of the Isthmus, had almost 17 inches.

c. "Officially" the dry season is from Christmas to mid-April. In reality the start and stop are unpredictable. For instance, the rains may stop in the first days of December, or they may continue into mid-January. The dry season has a substantial reduction of rain and cloud cover. The wind dire-tion changes and the velocity increased. The variation in sunshine and rain is indicated in table 3 and 4.

Table 3. Monthly Sunshine (In Hours) Cristobal harbor (1907-1970)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
Maximum	320	306	323	317	267	300	244	239	245	238	222	283	3134
Average	256	240	270	237	183	150	158	158	171	164	152	211	2350
Minimum	161	143	179	98	70	46	25	53	72	47	61	71	1675

Table 4. Monthly Rainfall (In Inches) Cristobal Harbor (1881-1970)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
Maximum	19.2	6.5	9.2	21.7	24.0	19.0	28.0	25.0	23.0	26.0	42.0	34.0	183.0
Average	3.9	1.6	1.7	4.2	12.8	12.1	16.0	15.2	12.6	14.3	22.4	15.9	129.4
Minimum	0.6	0.1	0.1	0.1	6.0	3.0	9.0	6.0	3.0	6.0	7.0	2.0	87.0

d. The rainy season, which generally begins in mid-April and extends through mid-December, has a tendency to divide itself into four parts:

(a) The first part - generally occurring in May - develops frequent rains with relatively high temperatures and more sunshine than the second and fourth part.

(b) The second part - generally June and July - has a continuation of frequent rains but lower temperatures and less sunshine than the first and third parts.

(c) The third part - generally August and September - has reduced rains, more sunshine, and slightly higher temperatures.

(d) The fourth part - generally October and November - has maximum rains, with the minimum of sunshine and lower temperatures.

e. Tables 2, 3, and 4 indicate that major variations in the weather exist within the Canal Zone. Rainfall and sunshine vary more than temperature and relative humidity. Data for tables 3 and 4 are for Cristobal (Atlantic side). Other stations have different totals, but the pattern of variability is the same throughout the Canal Zone. Extremes rather than averages should be considered.

f. Although there are only small seasonal differences in average temperatures, the daytime temperature has a marked difference from the nighttime temperature. Temperature is at a minimum at sunrise and rises rapidly to its maximum value just before noon each day. Once the maximum temperature is attained an oscillation occurs about that maximum until either a storm causes a sudden drop or until the sun angle is decreased, thus reducing its heating effect. After sunset the temperature drops slowly until the minimum is reached. The nighttime temperature drop may be interrupted by short periods of rising temperature. A frequency distribution of specific temperatures is shown in figure 3. Data for this figure were collected from the Environmental Data Base Program conducted at two sites on the Pacific side from 1964 through 1969. A close study of this figure reveals: (1) Daytime temperatures have a greater range than nighttime temperatures (2) Temperature ranges are greater during the dry season; and (3) The open site (Chiva Chiva) has higher daytime temperatures than are found within and above the forest (Albrook). Not shown in the figure, is that this difference increases substantially as one approaches the ground.

g. Most materials indicate a sensitivity to high temperatures. The surface temperature of material exposed to sunlight will be substantially higher than the ambient air temperature. This difference is dependent upon the physical properties of the exposed material such as reflectivity, color, internal heat conduction, etc. It should be emphasized that small climatic differences between sites or within the same site can have a great effect on the test item depending on its exposure to the sun.

h. Solar radiation measurements are difficult to evaluate or interpret. The entire radiation impinging on an exposed test item comes directly from the sun, reflected or modified by air and cloud ("sky radiation"), reflected and modified by the ground and objects, emitted by air and clouds, emitted by ground and other objects, and radiation from moon and stars. The amount from these sources varies considerably in short intervals, at short distances, over long distances, with season, and primarily with the time of day. Not only is the quantity of radiation varied, but also the quality is changed. The infrared (IR) portion of the spectrum mainly causes heating, but the existence of IR photography also shows that it has a chemical effect. The ultraviolet (UV) portion of the spectrum has mainly chemical effects ("actinic"), but it also produces warming, although this is negligible when compared to the heating from IR or visible light. The daily and seasonal variations of the global radiation (direct plus sky radiation) are related to but not strictly parallel to those with hours of sunshine. When there are clouds, a substantial amount of direct radiation penetrates the clouds. Over

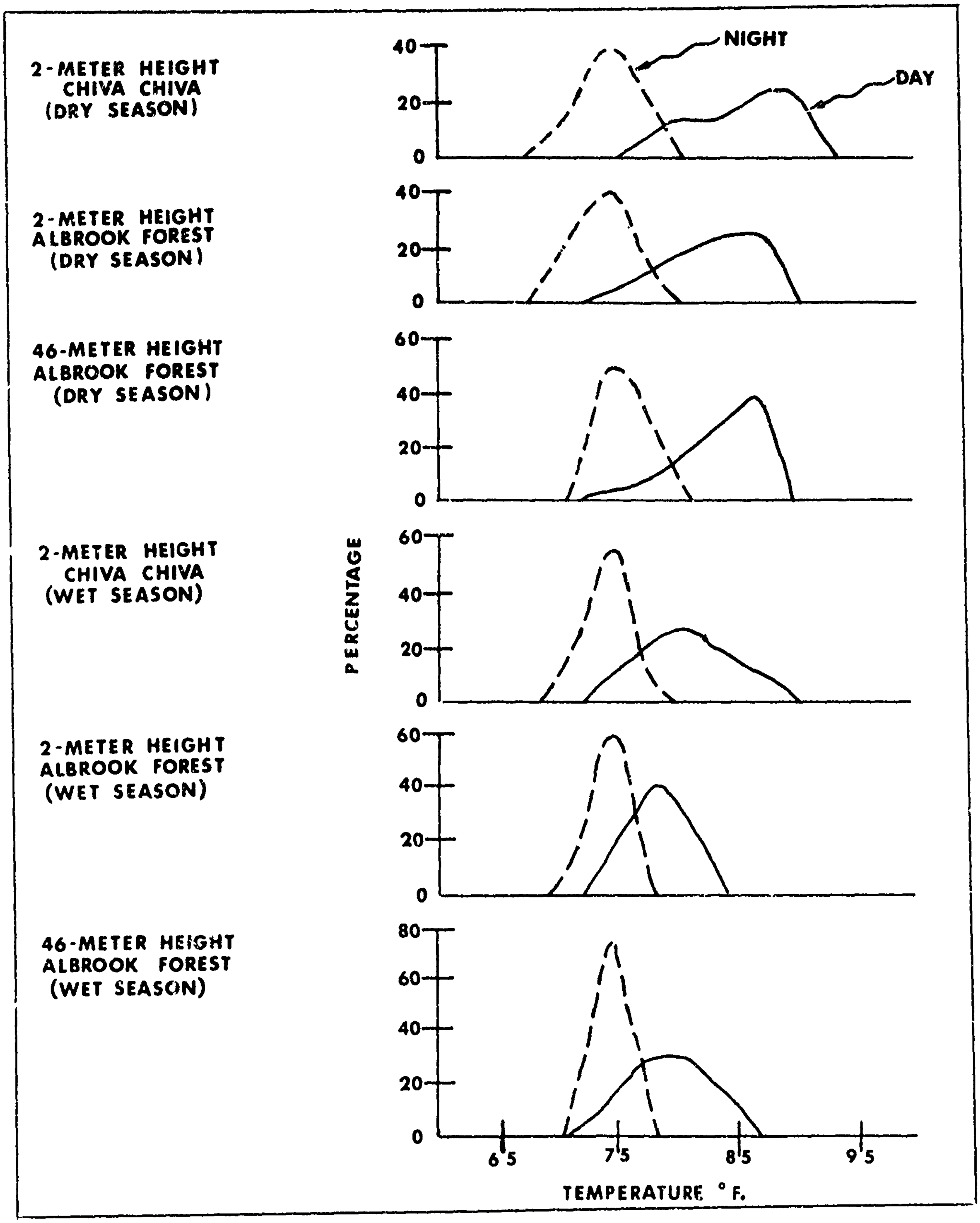

Figure 3. Percentage Frequency of Ambient Temperature

a period of years, the total direct radiation was measured at Coco Solo. It can be seen from figure 4 that a minimum of global radiation is present at Coco Solo in July. This minimum is caused by reduction in the amount of direct radiation while the indirect radiation remains almost unchanged. The measurements shown in figure 4 apply only to Coco Solo which is located near the northermost point of the Canal Zone (Atlantic Side). Extrapolation of these data to other areas in the Canal Zone should be made with caution since the accuracy of correlation is unknown.

i. The amount of moisture in the air (humidity) affects the comfort of personnel and has a direct effect upon the degradation process of materials. This is particularly influential in the tropics due to the association of high temperatures with high moisture content. As the moisture content in the air increases it becomes increasingly difficult to measure these levels quantitatively. Atmospheric humidity can be described in a multitude of scientific ways, each of which has a sound scientific application, but they are generally confusing to the layman. Each parcel of natural air contains some water vapor. The quantity of water vapor can be expressed as weight per unit volume (absolute humidity), or weight with respect to the weight of the moist air (specific humidity), or weight with respect to the air minus its moisture (mixing ratio), or by the partial pressure it exerts (vapor pressure). Absolute humidity and vapor pressure have upper limits which can be exceeded only for short periods and under special conditions. The upper limit depends only on temperature, and in the humid tropics a small decrease in temperature considerably lowers the upper limit. It is possible for a drop in temperature to lower this upper limit to a point where it reaches the actual amount of vapor pressure. A further drop in temperature would theoretically lower the upper limit below the actual value. Since this is virtually impossible, the excess water vapor will condense thus forming liquid. The temperature at which this condensation starts is called "dew point temperature," or more commonly just "dew point." Absolute humidity, vapor pressure, and dew point are equivalent terms of the same condition. The ratio, actual vapor pressure divided by maximum possible vapor pressure, is called "relative humidity" and is generally expressed in percent. By definition, relative humidity can be as low as 0 percent and no higher than 100 percent. The latter case is referred to as the "upper limit" and is technically named "saturation pressure." The difference between actual vapor pressure and saturation pressure is called the "saturation deficit." Typical differences in humidity between the Atlantic and Pacific sides are indicated in table 2 for the rainy and dry seasons. Although the data are biased toward the higher values, they still indicate the relative difference.

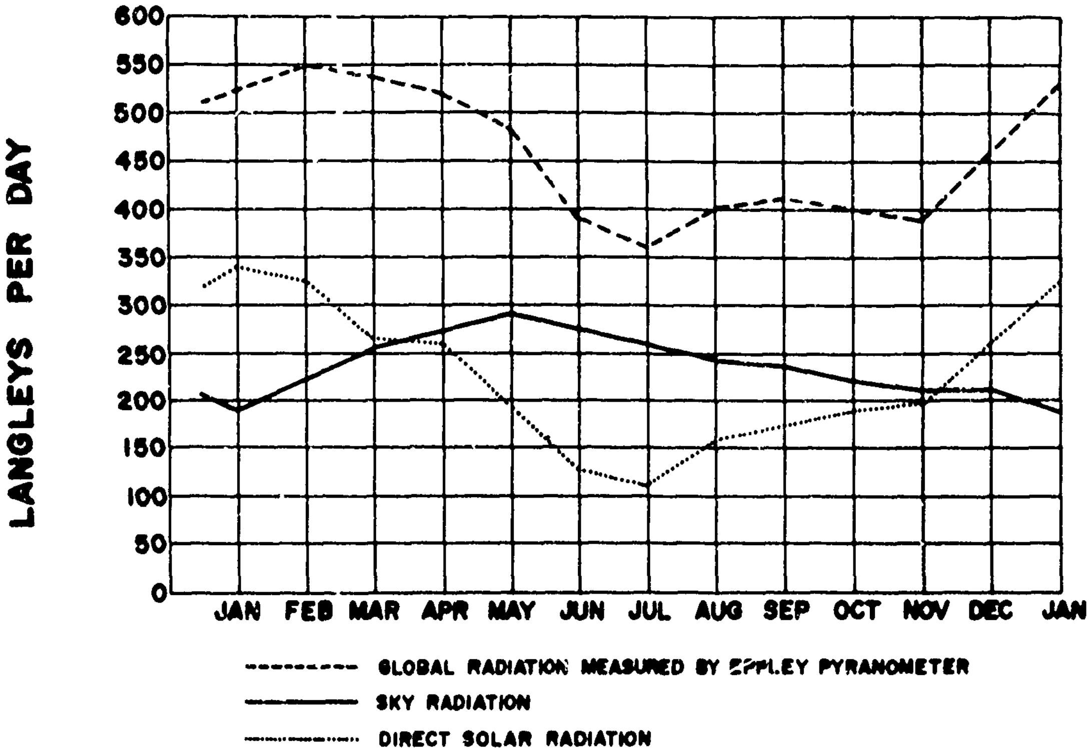

Figure 4 Monthly Variation of Solar Radiation at Coco Solo

Figure 5 compares the variation of the total radiation of Fort Sherman, Fort Clayton, and Coco Solo with the theoretical amount at the outer edge of the atmosphere. The difference between the measured and theoretical curves is due primarily to clouds reflecting radiation back into space, and to a minor degree by air and clouds absorbing radiation. Note that Coco Solo has the most radiation throughout the entire year,and Fort Clayton has less than Fort Sherman except for the period from December through February. Also, figure 5 shows that there is 15 to 20 percent less radiation at ground level during the wet season than during the dry season. This figure alsc shows that ground radiation averages 65 to 70 percent of the outer atmosphere global radiation, while during the wet season the ground radiation averages only 45 to 50 percent. An hourly analysis of radiation data indicates that Fort Clayton has a higher percentage of radiation before noon and a lower percentage after noon, while the opposite occurs at Fort Sherman. This indicates that sunshine is more probably before noon on the Pacific side whereas the opposite is probably on the Atlantic side.

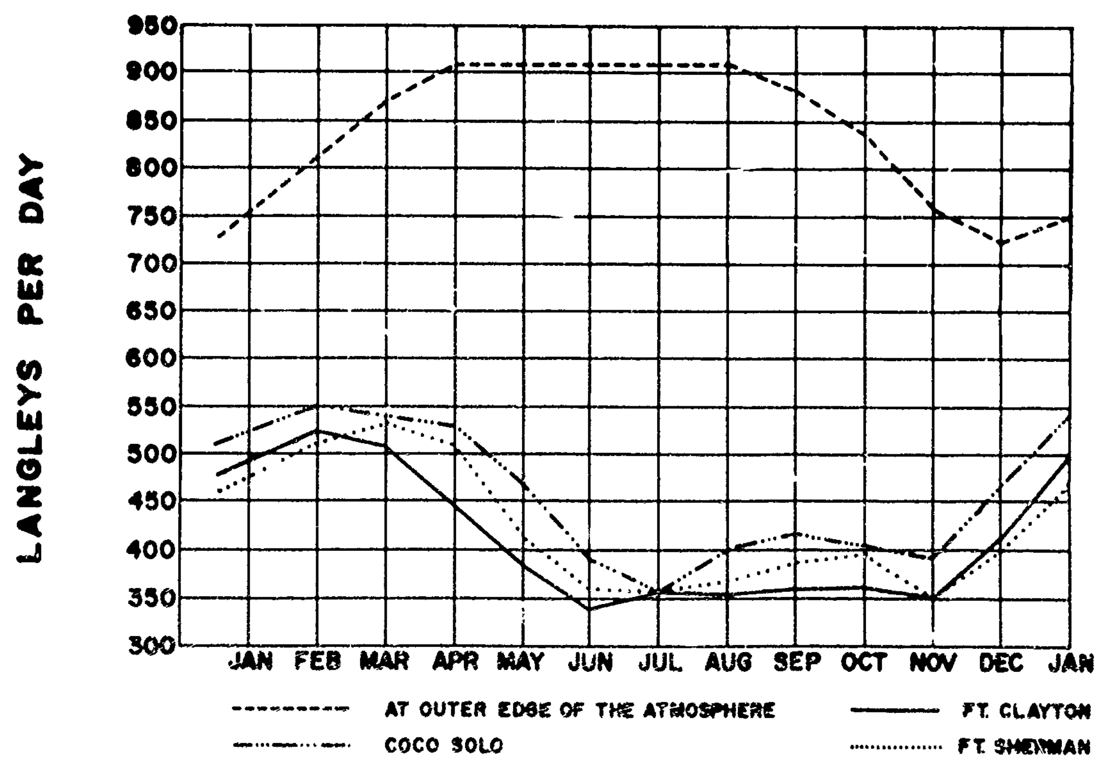

Figure 5. Monthly Variation of Global Radiation

It is possible to calculate the amount of radiation at the outer edge of the atmosphere that impinges on a plane at any inclination. Only the horizontal plane faces the entire celestial dome and therefore it receives the maximum radiation. Inclined surfaces are more complicated to evaluate. As an example, the radiation estimates for vertical walls facing the four cardinal points are listed in table 5, together with the radiation averages measured on a horizontal plan at Coco Solo. Table 5 illustrates some typical features of the tropics. For instance, the north exposure has higher radiation in summer than the south exposure because the sun culminates, in Panama, in the north from 14 April through 31 August.

Table 5. Mean Monthly Radiation (Solar Plus Sky) At Coco Solo (langleys*/day)

Plate Orientation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Horizontal	519	551	545	530	470	380	353	399	412	400	394	459
Vertical N	91	113	136	169	216	209	175	165	127	110	102	106
Vertical E or W	382	416	429	416	383	324	307	335	341	324	317	359
Vertical S	383	280	190	135	139	129	125	128	135	179	235	321

*1 langley = 3.687 BTU/sq ft

NOTE: The radiation on the horizontal plane is a direct measurement. The radiations on the vertical planes are estimated values.

j. During cool periods, surface temperature is usually lower than the air temperature. Most often the cool periods occur at night, and the surface temperatures fall below the dew point of the overlying air due to loss of heat by radiation. This causes the water vapor to condense on the surfaces as dew. The amount of cooling of the surface depends on its physical properties. Often the presence of quantity of dew varies depending upon the orientation of the surface. Although this phenomenon is observed regularly, the contributing factors have not been quantified. Because of the high moisture content of the air, dew formation occurs on practically all surfaces almost every night, even during the dry season, and is a substantial contributor to fungal growth and the degradation of materials.

k. Fog occurs sometime during the early morning hours and is usually confined to the Panama Canal and Chagres River areas. Fog may also drift through the crows of the trees during and after rain. Generally, the fog dissipates by midmorning.

l. Rainfall is extremely variable in the Canal Zone in both location and time. On the average, the Atlantic side of the Zone has an annual rainfall of approximately 130 inches. The wettest month is November averaging 22 to 24 inches, and the driest months are February and March averaging 1 to 2 inches. On the Pacific side of the Zone, annual rainfall averages 70 inches. The wettest months are October and November averaging 11 inches each, and the driest months are February and March averaging less than 1-inch per month. The maximum average rainfall generally occurs a half month earlier on the Atlantic side. The ocean areas have the greatest rainfall frequency at night, while the mountains have the greatest frequency around midday. Since the Canal Zone is situated between two oceans and has a mountainous interior, rainfall can occur at any time during the day and night. However, rainfall during certain hours is more prevalent according to location, season, and weather patterns. Figures 6 through 9 plot average and extreme conditions of rainfall distribution throughout the Canal Zone.

m. The Canal Zone is in or near the Atlantic trade wind belt for a considerable part of the year. However, these trade winds have traveled a great distance over water prior to being intercepted by the Central American land mass, and therefore have lost part of their impetus and have had their characteristics modified. The local and eastern Pacific wind systems frequently weaken, overcome, or replace the trade winds. When well organized, the Pacific winds are sometimes referred to as "monsoon." Frequently a "no man's land" of light winds separates the Pacific monsoon system from the Atlantic trade wind system. This area is characterized by low clouds, frequent rains, and muggy air and is referred to as "Intertropical Convergence Zone" (formerly referred to as "the doldrums"). This zone moves back and forth across Panama as the seasons change. During the dry season the trade winds are dominant. Wind speeds of 15 m.p.h from the north-northeast are normal at the Atlantic Coast.

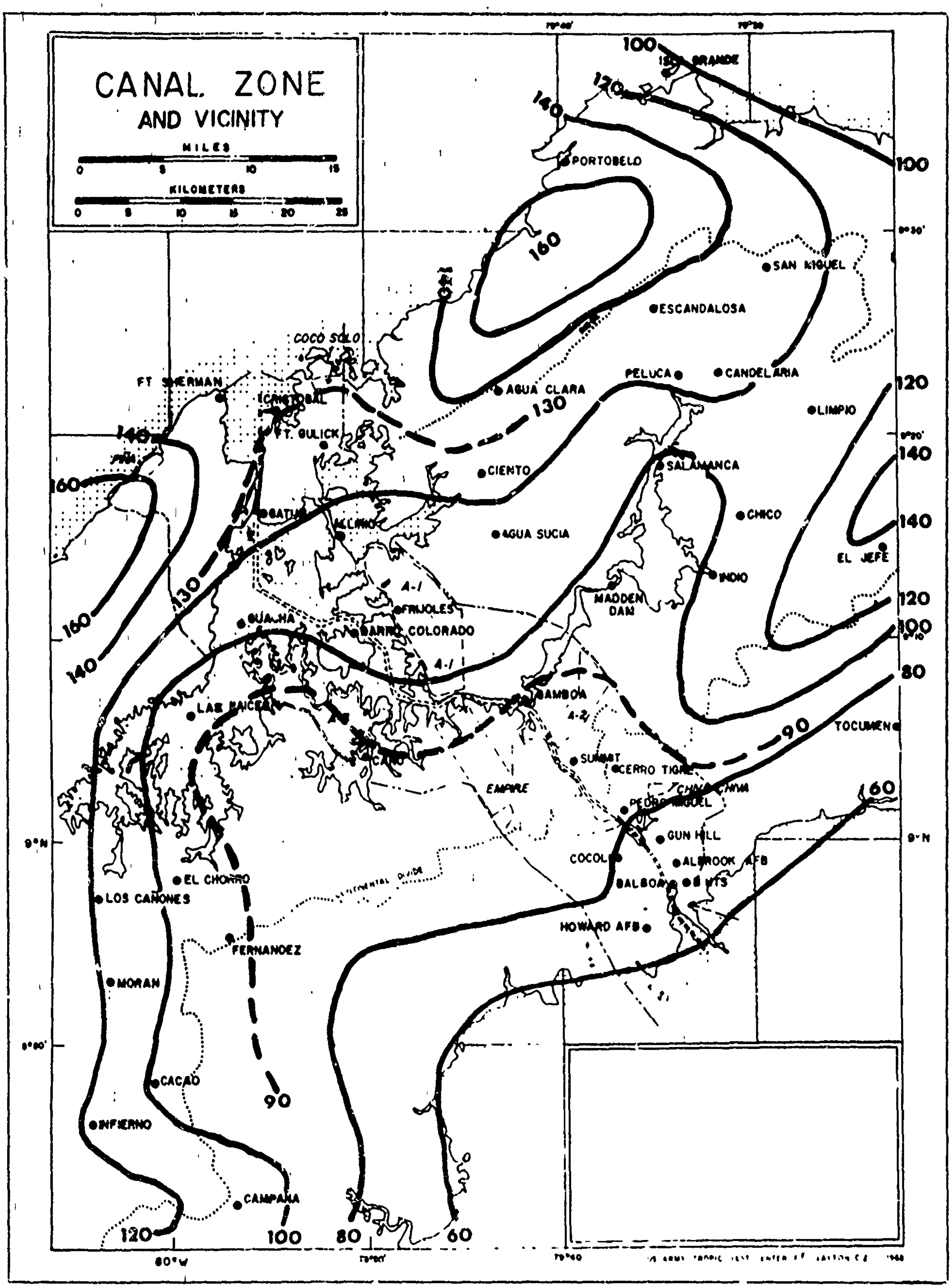

Figure 6. Mean Annual Rainfall (Inches).

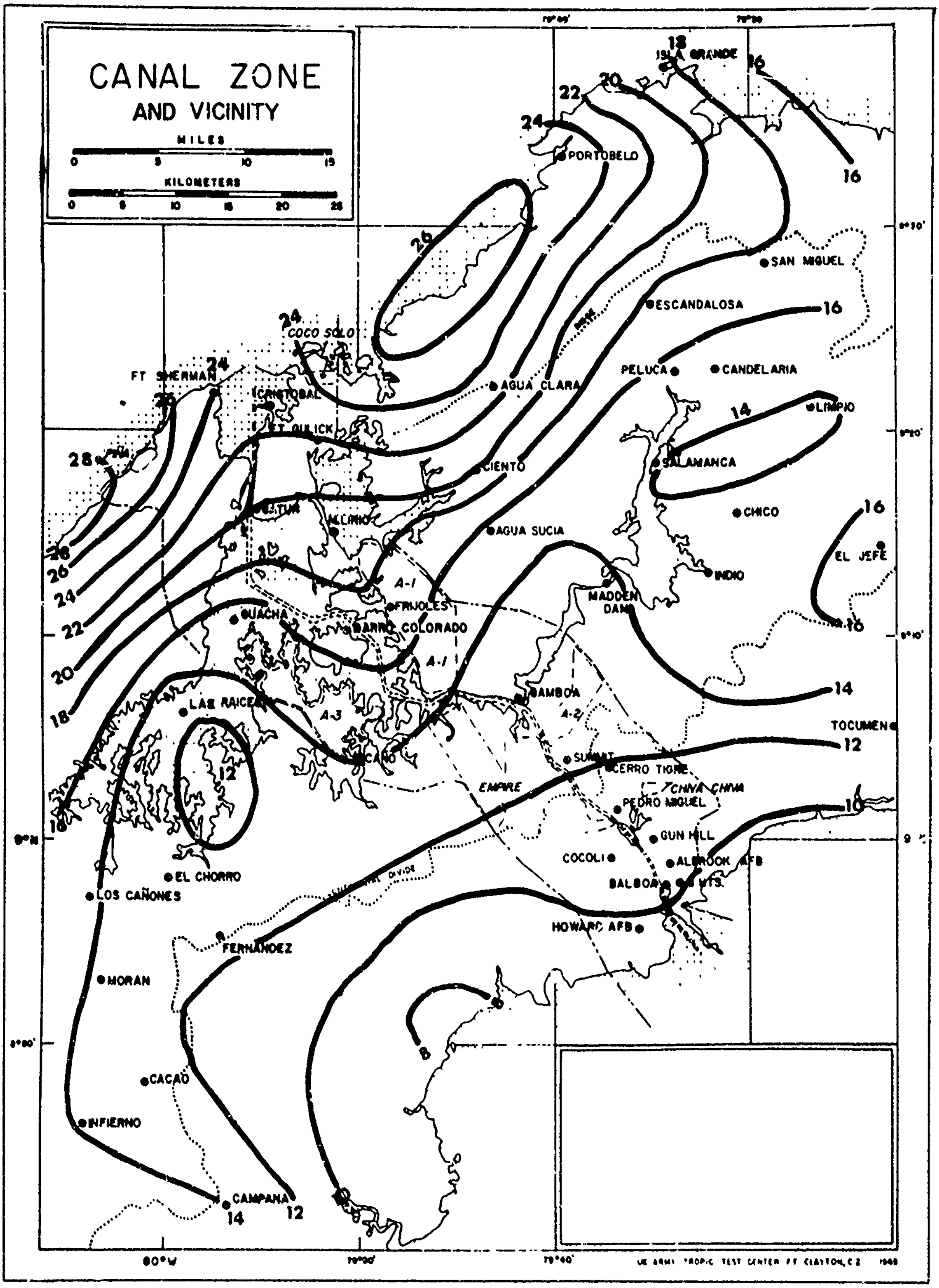

Figure 7. Mean November Rainfall (Inches).

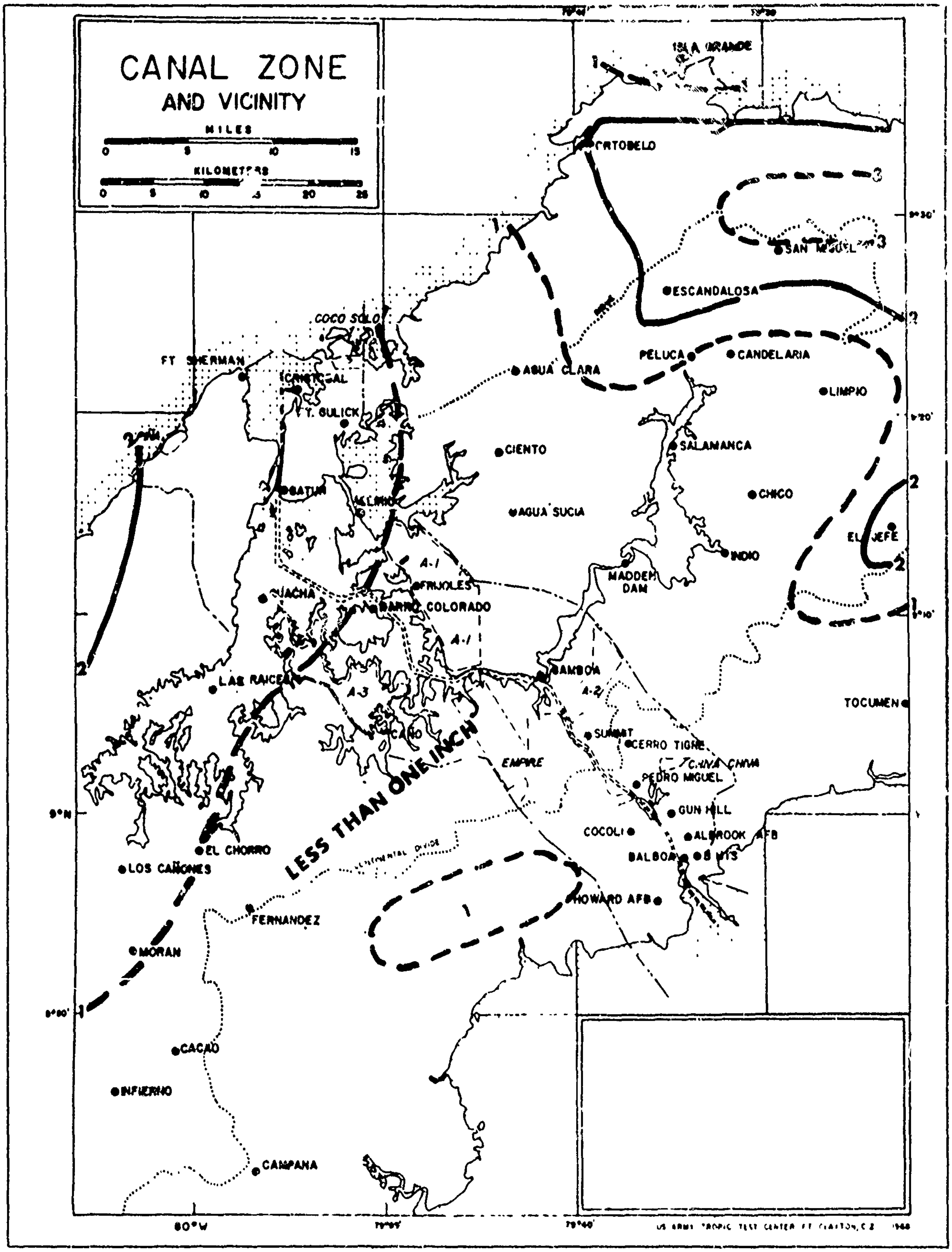

Figure 8. Mean March Rainfall (Inches).

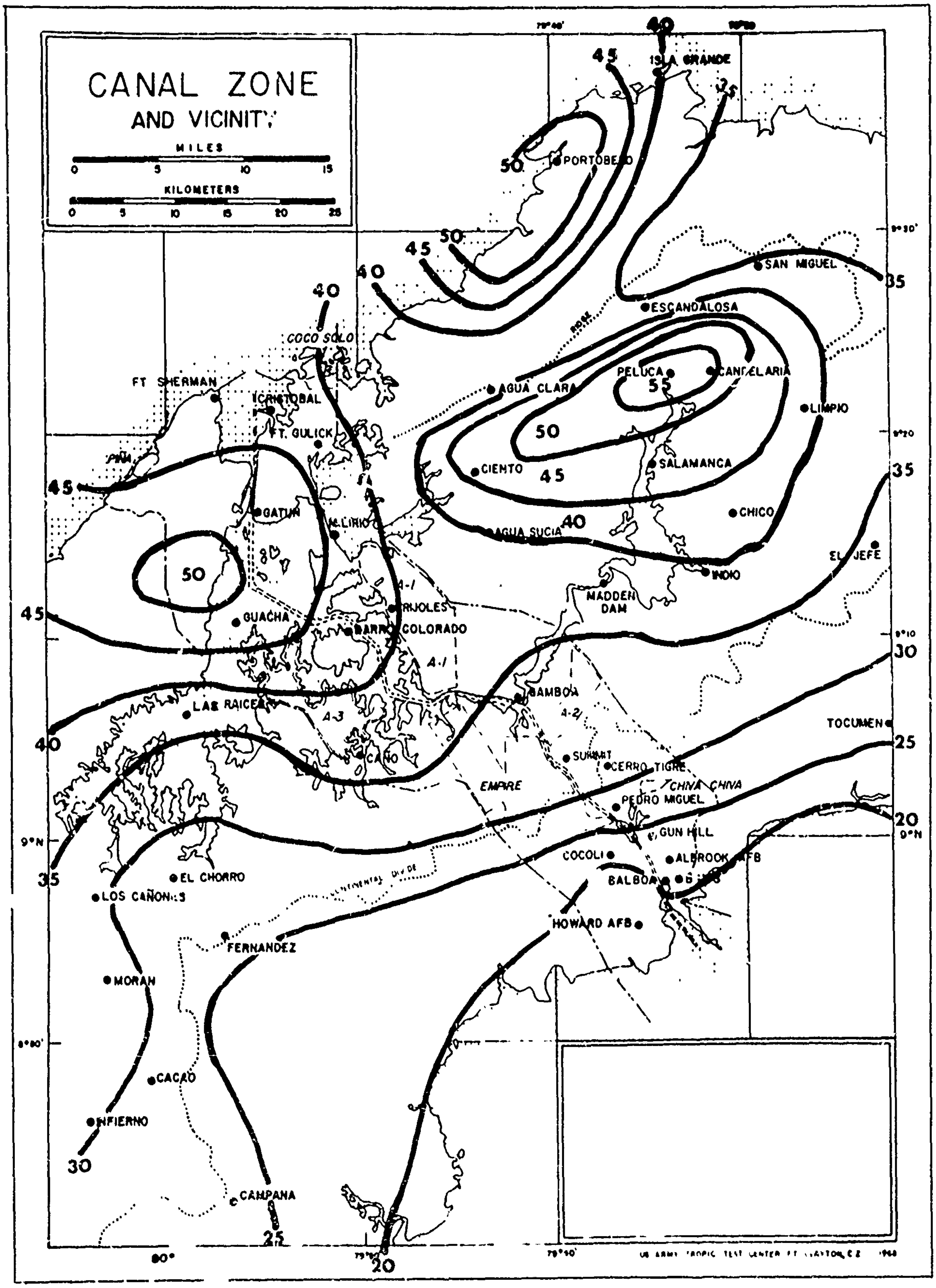

Figure ° ighes' Total Rainfall for any Calendar Month (Inches).

The speed decreased rapidly inland and veers so as to arrive as northwest winds at the Pacific Coast. During the rainy season the wind speeds are generally quite low, calms are frequent and wind direction is variable. Occasionally the pattern is broken by gust at the onset of thunderstorms, by tornadoes, or by waterspouts. The highest recorded wind speed, averaged over an hour, was 30 m.p.h. Local wind gusts have been so strong that they have uprooted trees, but widespread strong winds are not known in the Canal Zone. High surf may result from waves generated by distant hurricanes, particularly on the Atlantic Coast.

n. Atmospheric ozone is less than in the United States and Alaska. The mean and extreme ozone levels are smaller than the smog-free areas of Arizona, Alaska, and Massachusetts. The ozone content in Los Angeles has been measured, in periods of smog, as more than 10 times the Canal Zone average. The ozone content in the Canal Zone has a high correlation with wind speed. This indicates that the ozone descends through turbulence from upper layers of the atmosphere, and is not produced locally in the lower atmosphere. Therefore, the greatest ozone content is observed in the dry season when it averages 1.5 to 2 parts per hundred million. In the rainy season it drops to 1 part per hundred million.

o. Hurricanes with high winds never reach the Canal Zone. Tornadoes, waterspouts, and hail are rate phenomena. The only storms with significant consequences are thunderstorms and temporals. Flooding is the most hazardous potential of both of these storms, although damage from lightning cannot be ignored. Thunderstorms are characterized by wind gusts at the beginning, local (heavy) rain and a drop in temperature. Lightning and thunder may be either heavy or light. Thunderstorms can last for several hours and affect a large area, or they can be of short duration and extremely localized. Very few rains are completely free of some electrical activity. Temporals are less frequent than thunderstorms. Temporals are characterized by large size (area), even falling rain, no strong wind gusts, little or no electrical activity, and a duration of many hours. Both temporals and thunderstorms can cause flooding; the former because of the duration of rainfall over a large area, and the latter because of the violence of the rainfall. Temporals keep the temperature low. On these days, the highest daytime temperature may be lower than the nighttime minimum. Local storms cause the excess tropical heat and moisture to be transferred to the cooler upper levels of the atmosphere. Larger storms serve the same purpose but are produced by the interference of air masses. When one air mass dominates, the storm moves along rapidly and does not influence a specific geographic area except for short periods. However, from time to time both air masses are equal in strength, in which case the storm becomes stationary and may hover at one location discharging a large amount of rain on the area. Beginning in November, Canadian air masses more frequently invade the Panama region. Each assault is accompanied by large quantities of rain. Following a successful invasion, the rain

dissipates and is replaced with sunny weather accompanied by northerly winds. As the wet season draws to a close, the Canadian air masses dominate more frequently until they become the prevalent feature of the weather of the dry season. The Canadian air mass influence lessens in April as the moist equatorial air pushes northward to a point near or north of Panama and the rainy season begins. The Canadian air masses and trade wind air travel a long way over warm tropical waters so that their temperature and moisture near ground level are similar to those of the equatorial air. The difference in cloudiness, sunshine, and rain is contingent on the temperature and moisture in the higher levels.

5. Degrading Factors and Elements.

a. There are several insects native to Panama, some of which are destructive to materials, while others cause only deterioration.

(1) Termites are spectacularly destructive insects. The worst of these undoubtedly the subterranean termites. These social insects live below the ground, but do most of their damage above ground where they build large burl-like nest. These nests are connected to the ground or the feeding site by mud tunnels which usually are the first indication of their presence. The top fominant subterranean termites in Panama are of the Nasutitermes and Coptotermes genera. The Coptotermes species is called C. niger, because it has a black head. Entomologists are not in agreement about the ability of termites to digest wood directly, however they do eat wood and derive nutrition from it by one means or another. Subterranean termites will abandon an area if they are continually disturbed. In general, they do not eat away enough wood to cause spontaneous collapse of a structure, but cause so much hidden damage that any slight additional load results in collapse. The other termite found in the Canal Zone is the less common dry wood termite which does less damage in comparison with the subterranean variety.

(2) Roaches, while not usually thought of as destructive, do great damage to textiles, and especially clothing. They do not seem capable of digesting the cellulose in fabrics of books, but can digest the bits or remnants of human food which almost always are present on textiles in contact with humans. The roaches eat the fabric in order to get the nutritious food stain.

(3) Beetles inhabit this area and several of the species are wood borers, but they are not known to damage military equipment and so are not discussed further.

(4) Spiders are numerous and range from the poisonous tarantula to other very small and harmless arachnids. Spiders can put military electronic gear out of operation merely by spinning a web within a cabinet where the strands of the web can act as an electrical short or a shunt.

(5) Other insects cause other indirect damage within electronic gear by their droppings or by the bacteria carried on their feet. As these substances are left behind, they are found by scavengers (usually fungi, but at times bacteria) and the metabolic products of the scavengers either corrode metals, such as soldered joints, or cause electrical shorts. Other insects disable electrical gear by spinning cocoons, or, as in the case of ants, building nests within the consoles.

b. Countermeasures against termites, roaches, and beetles involve moving their targets frequently. This procedure will defeat them. However, when this is not practicable, poisons of the halogenated hydrocarbon family can be employed against them. Sometimes high boiling fractions of creosote are used against termites in wood, while copper, mercury, and zinc compounds are used in fabrics. Some of these compounds are poisonous or toxic to humans, therefore they must be used with caution.

c. Fungi can be selected as the one group of organisms which has received the most attention in recent years with respect to deterioration problems. A good deal of this research interest arose from the widespread fungal attack on equipment used by the Armed Forces in World War II. To evaluate and prevent the damage caused by fungal growth, it is necessary to understand some biology and biochemistry of the fungi. The term fungus is a very broad designation used to describe a large and heterogeneous group of organisms within the plant world. (Fungi are plants which lack the ability to produce chlorophyll.) Those fungi of greatest interest to deteroration specialists are mostly either molds or destroying fungi. The term mold, although not exactly defined in a biological sense, is used by both the biologist and the layman to refer to small nonparasitic fungi. The term mildew is used synonymously with mold. Fungi of one sort or another may be found in soil, water, and air over a large portion of the earth's surface. Some types occur in and upon living plants and animals, several are pathogenic to man such as Trichophyton mentagrophytes which causes athlete's foot. Others are responsible for the decay of vegetation, while thousands of different species play a prominent role in the complex biochemical transformations of organic matter present in the soil. Most fungi are so small that their characteristics structures can be identified only with the aid of a microscope. The wood rotting fungi, however, constitute the principal exception to this generalization; their fruiting bodies are in many cases quite large, often measuring from one to several microns across in their largest dimensions. In general, a fungus is made up of two different kinds of structures - vegetative and reproductive. The principal vegetative structure is the hypha (plural hyphae), essentially a threadlike growth filament. A group of hypha is referred to collectively as the mycelium. One of the principal reproductive fungus units is the vegetatively formed conidiospore. One of the principal reproductive fungus units is the vegetatively formed conidiospore. This unit

varies greatly in size from less than one micron to a few giant types 500 microns in length. In shape, spores may be spherical, oval, kidney shaped, elongate, needle-like, discoid, or irregular in form. The size, shape, and manner in which spores are attached to the hyphae are important characteristics for identifying the fungi. A fungus has two Latin names, e.g., Pullularia pullulans. The first name denotes the genus, which is always capitalized, the second, the species which is never capitalized. Both genus and species are usually underlined. Many items, especially those exposed in the humid tropic environment,are known to be degraded by fungal growth. The test items composed of or containing the following substances are prime targets for microbial deterioration: petroleum products; textiles, e.g., sandbags, coated fabrics; canvas; ropes and cordage; nylon; paint; electronic equipment; polymeric materials; wood, paper, and optical material. Fungi can cause corrosion of metals either by excreting corrosive substances or by creating a differential concentration cell by means of their mycelial mat.

d. Animals that cause damage to military equipment in Panama are usually the small ones such as rats and mice, both of which abound in great numbers, Ordinarily the damage they cause is by gnawing through wood or some such barrier to reach food or water, but often they and other small to medium sized animals, both rodents and others, seem to have their curiosity excited by some strange object in their territory. They then gnaw or nibble on the object in an effort to find out whether it is edible. Often the object gnawed or nibbled is a communication line on the ground. Cases, where insulation has been chewed off causing shorts to ground, are beyond counting. Cases, where the wires have been bitten through completely, are numerous. Land crabs abound in Panama, especially on the Atlantic side. These creatures live in burrows on marshy land during the dry season, and leave their burrows and move to the sea in May as soon as the rainy season becomes advanced. They seem to breed before this time because females covered with eggs are often seen on the move. Also, they seem to have favorite places for crossing roads where they are crushed by vehicles. The road to Galeta Island near the Galeta Point facility and the Fort Sherman road across the Mojinga Swamp have very obnoxious aromas when the migration is in progress. These nuisances also attack military equipment of all kinds which may be in contact with the ground and are of a size which their claws can accomodate. They have been known to bite through telephone and other such cables and through fabrics. There does not seem to be any effective countermeasure.

6. Properties of Materials, Protection, and Degradation.

a. General.

(1) All materials undergo degradation due to various physical, biotic, and environmental factors. The degree of degradation is dependent upon many factors. Prominent ones are: material properties; surface treatment; and environment. All material has a specific range

of conditions under which it exhibits and/or maintains given characteristics. In selecting materials of construction for any given set of conditions, we attempt to exploit the desirable characteristics and reduce to a minimum those which are undesirable. Active (control of the environment) and passive (surface coating or changes in the material) methods are utilized to influence these factors. Success in minimizing degradation is usually indicated by the useful life of a given piece of equipment. Historically, attempts to reduce the deterioration process have been passive in nature. Militarily, passive methods have proven to be the most popular methods of control. In all probability this will continue to be the preferred method utilized in the interest of economy, conservation of strategic material, and the reduction in the overall complexity of weapon systems.

(2) The major factors contributing to degradation are: radiation; ocidation; electrolysis; and biotic and chemical attack. Many of these phenomena are so interrelated that they are inseparable and therefore must be considered collectively. Climatic or environmental effects are examples of these interrelated phenomena. This is the most notable phenomenon in the tropic region. and the one with which the Tropic Test Center is greatly concerned. Climate has both direct and indirect influences upon the other factors of degradation. In spite of passive control measures the degradation process continues and each class of material exhibits its own specific degradation pattern for any given environment. The following is addressed specifically to passive control of degradation.

b. Elastomers.

(1) Elastomers are those substances which are either rubber or exhibit rubber-like properties. Natural rubber, which is the coagulated and smoked sap of the rubber tree, was for a long time the only important elastomer. In 1932 a way of producing a rubber-like material developed based on acetylene. This compound became known as neoprene and could be mixed with hardeners, treated, and cured (vulcanized) like natural rubber, but had superior resistance to degradation by petroleum products and other chemicals. This "breakthrough" was followed by the development of a number of other elastomers which had different characteristics. All these elastomers required vulcanization, which basically is the process of mixing the elastomer with sulfur and subjecting the mixture to heat, thus converting the weak compounds into usable products. It was soon determined that by adding certain organic chemicals called accelerators to the elastomer-sulphur blend, the vulcanization process could be shortened drastically. Other investigations established that in some cases the addition of colloidal carbon increased strength and abrasion resistance. By increasing the amount of sulphur and vulcanization time, hard rubber is obtained; and by manipulating all the variables, elastomers can be given a great number of different properties, each tailored to a specific use. The elastomers, both natural and synthetic, are also members of a family of compounds called polymers, i.e. individual molecules naturally joined to one another to form single, gigantic molecules.

(2) Many elastomers are susceptible to ultraviolet radiation and ozone deterioration and also fail due to constant flexing. In vulcanized elastomers, the vulcanization process does not stop completely after manufacture but continues slowly even under ambient temperatures. As most elastomers self-vulcanize (more commonly called aging) they become less flexible and may fail due to brittleness or inability to yield to a blow. However, there are some elastomers, e.g., polyurethanes, in which the continued polymerization is an added advantage as physical properties (tensile strength, modulus, tear strength, etc.) show an increase for several years following fabrication. In Panama vehicle tires of natural or synthetic rubber generally do not last for much more than 12,000 miles, while in CONUS up to 30,000 miles is not uncommon. The reasons for this mileage difference is not fully known, but data being accumulated at USATTC are contibuting to our knowledge of the phenomenon. Ultraviolet (UV) radiation was considered but the hypothesis was abandoned when comparisons were made with other areas which have at least the same daylight UV content. Certainly some rubbery materials can last a long time here under some conditions. Tires made in World War II have been observed in the jungle at Fort Sherman and the rubber was still elastic and lively many years later. On the other hand, some of the newer elastomers will degrade in sealed containers on the warehouse shelf. Generally, these are elastomers that are not heat vulcanized, instead chemicals have been added to the gum to bring about a process similar to vulcanization.

c. Wood and cellulosic materials.

(1) The latest proposed method to protect wood from termite damage is to modify the wood chemically. This is done by treating the wood so that the cellulose is changed into a related compound which cannot serve as food for the insect. This is a new idea and the techniques for the treatment with the best modifiers have not yet been established. The chemicals used to modify southern pine were various isocyanates. Wood so treated is indistinquishable from ordinary wood in appearance. This technique avoids all problems of toxicity, loss of potency, paintability, etc., and does not seem to have an effect on the strength of the material.

(2) Wood and cellulose materials are degraded in two ways which are of special importance in the humid tropics, i.e., rotting and termite attack. One might also consider fungal attack, but generally such damage would be considered as rotting. Much has been said about termites and their destructiveness but those remarks were concerned mainly with wood. The termite will consume anything that is cellulosic, which includes: paper; cardboard; cotton; hemp; and other similar substances; regardless of shape, size or form. These pests can destroy a shipping container, or an ammunition box, a peg or pole or a rope just as easily as they damage the wooden parts of buildings. They work unseen and unheard and never consume the exterior portions of the object they damage. As a result timbers and structures may appear perfectly sound even though only a structural shell exists. Termites display a marked selectivity

and will attack anything that is cellulosic but do so in a preferential manner. Some woods have some natural resistance to termite attack while others seem to actually attract the insect. Non-native woods, such as those from the United States, are especially attractive to the Panamanian termites. U.S. woods are among the favorite foods of Panamanian termites, and this has increased maintenance costs here because such woods have been used in the construction of housing and other structures in the Canal Zone. Since the 1940's treated U.S. woods have been used and more durable structure have resulted. The treatments usually utilize pentachlorophenol, tetracholorophenol, and similar effectives, but rather primitive repellents. Where the structure is not to be painted creosote is often used, but creosote is a mixture of a large number of rather similar compounds, only a few of which have any value in preventing termite damage. It has been proven that only the light fractions of creosote are effective as a termite repellent. When the structure is to be painted, other repellents must be used. There are a good many of these, and some are so toxic to humans that they can be used only in selected cases. The compound called gamma isomer of benzene hexachloride has proven to be as effective as 10 times its concentration of creosote, and it presents no problems to the painter. It is soluble in almost any organic solvent and can be applied by brushing, dipping, or by pressure or vacuum impregnation. It is very slightly volatile even in the solid form and will eventually vanish. Its toxicity to humans is unknown and stringent safeguards need to be used in applying it.

d. Textiles.

(1) Natural Fiber Textiles.

(a) Chemicals added to natural textiles must have special characteristics. For one thing they must be insoluble to water, or nearly so, otherwise laundering will remove them. Virtually all the compounds used to defeat termites in cellulosic materials can be used in textiles made of natural fibers, but laundering and intimate contact with human tissue may make them unsuitable. A new method is to coat the fibers with plastic before weaving.

(b) Natural fiber textiles are attacked by roaches, termites, fungi, algae, bacteria, and some animals. They are also damaged by UV, intense heat, and by abrasion. They can be protected temporarily by the addition of certain chemicals. Two of the best substances to prevent attack by insects, microorganisms, and animals are copper-8-quinolinolate and naphthylene.

(2) Synethetic Fiber Materials.

(a) Makers of synthetic fibers add chemicals to the substances which absorb the ultraviolet spectrum and therefore prevent such rays from damaging the fibers. Many such chemicals are known

and used with a wide diversity in the relative effectiveness of each. All nylons are not the same even when the same type of nylon is used for a similar article, one batch may have been treated with different chemicals during manufacture of the threads while they are identical in other respects.

(b) Synthetic fiber materials suffer only incidental damage from animals. Animals and insects will chew holes in them if they constitute a barrier; this is merely an attempt to remove an obstruction, or it may be merely curiosity. Many of these fibers, however, are very susceptible to damage by sunlight, especially the ultraviolet portion. Textiles of man-made fibers are attacked by microorganisms such as fungi, algae, and bacteria but it is not certain in all cases whether such microorganisms are actually consuming the material or are merely making use of some nutrient which happens to be attached to the material. Since these fibers are plastics, they deteriorate in the same way as plastics. Much damage is caused by animals, chewing insects, and land crabs. However, their principal failure mode is deterioration due to actinic damage caused by the ultraviolet portion of sunlight. In general, they endure in shady places and some endure in sunny places while others fail in a very short time. Evaluating failures in the tropics is complicated as differences in durability of man-made fabrics are noted between those of different types of material used to make the fiber as well as those which are made of the same material.

e. Leather.

(1) Characteristics of leather and their preservation are a problem in the tropic. This was addressed by the U.S. Army Natick Laboratories as long ago as 1955. During 1954 and 1955, specimens of leather were exposed at USATTC's Galeta Point facility. A large number of compounds were tested and several were found that would inhibit fungal attack (mildew) of shoes and other leather goods.

(2) Leather is used in everyday life in Panama and spectacularly attacked by fungi. This continues to be true in spite of a great deal of research into preservation methods and preservatives. It will be noticed that the polished parts of shoes or other leather articles are not usually attacked. This is because the wax in the polish is not a nutrient and the mildew producing organism (fungi) cannot thrive on such areas. The inner surfaces of shoes, often the soles, however, will rapidly become thickly coated with a fuzzy growth of fungi. Generally fungi requires a relative humidity exceeding 60 percent, therefore this growth will not be observed in air-conditioned areas. The rate of fungal attack on leather depends on many factors, but the method of tanning seems to be the most important determinant. Leathers tanned with vegetable tanning agents seem far less resistant to biotic attack than leathers tanned by inorganic chemicals, the so-called chrome method. It should be remembered that leather is animal skin and that the same fungi that grows on leather will grow on human skin also. This means that handling mildewed leather items can cause fungal infection on the

user. Leathers once exposed to and infected by fungi remain infected for long periods of time even if removed from an area where fungi flourish. Leather articles that had been exposed to the Panamanian environment and then kept in an atmosphere where the humidity is very low immediately became fungi laden when transported to other areas removed from the dry atmosphere (a case in point was a camera case whose user received a painful case of dermatitis). The ability of fungal spores, hyphae, and mycelia to remain dormant but viable for long periods must always be kept in mind. They have been known to survive for years sealed in glass without any source of food and even under subzero temperatures.

f. Metals.

(1) Metals encompass a multitude of elements and alloys which exhibit radically different properties and costs. Often we must compromise some properties in order to choose a material with other required properties. The structural metals are a good case in point. While the common steels are relatively inexpensive and strong they are very suceptible to corrosion. Large amounts of money are continually spent in attempts to eliminate or reduce this corrosion to tolerable levels. Corrosion is usually associated with oxidative degradation and the most common form is the rusting of iron or its alloys.

(2) There are several kinds of corrosion and some 30 to 40 factors interact to produce these different varieties. Oxygen is the main contributor to corrosion of the common metals such as aluminum, magnesium, copper, steel, and zinc. This oxygen is usually supplied from moist air or from dissolved oxygen in an aqueous solution and is often accelerated by the presence of microorganisms. Some of these oxides have beneficial characteristics and prevent further corrosion. In other words, they form thin films on the metal which prevent or retard further reaction. This is the case with aluminum, chromium, nickel, and various stainless steels. The formation of such oxides, in the case of aluminum and its alloys, by a commerical process called anodizing, produces an extremely adherent and abrasive resistant coating of aluminum oxide on the surface of articles so treated. The treatment of stainless steels usually with nitric acid forms a resistive oxide coating which further resists oxidation. Mild steels are "blued" or Parkerized with metallic salts or phosphoric acid to resist further oxidation similar to anodizing. Oxidation or rust produced on such metals can be caused by direct combination with atmospheric oxygen as mentioned, but such attack is slow at low temperatures. For rapid corrosion of iron and steel and presence of moisture of water, preferably at elevated temperature, is essential. With water present, either as a vapor or a liquid, a fast chemical reaction takes place and one or a number of the possible oxides of iron are formed. As noted, the oxides of aluminum and other metals prevented further corrosion but such an effect is rarely observed with iron or the so called non-stainless steels. The reason for this seems to be that the oxides of aluminum, or other resistant metals, are crystalline and occupy about

the same area as the base metals; there is no overcrowding of the surface and therefore the oxide crystals sheath the base metal. With iron and low alloy steels the corrosion products require much more area than the base metal, over-crowding occurs and the corrosion products fall off with the result that new material is exposed to attack. One oxide of iron does have a crystalline structure and occupies about as much surface as the base metal, so it protects the base. This oxide rarely forms, still, the fact that it does form explains why we occasionally find very ancient ferrous articles in climates where iron normally corrodes rapidly. Since it is difficult to generate protective oxide coatings on iron and low alloy steel, other techniques are required to protect articles made of these metals. Such techniques always take the form of treating the surface in some way. For instance, a ferrous alloy can be plated with chromium, nickel, zinc, or some other corrosion-resisting metal or it can be galvanized by dipping in molten zinc. While zinc makes an excellent coating metal for ferrous metals, (that produced by electro-plating) and if properly done and of sufficient thickness, is superior to the coating produced by the dipping process. When iron or steel is dipped into molten zinc a heavy and protecting coating is produced. However, at the same time, an alloy (actually an intermetallic compound), is formed at the interface between the metals. This compound is brittle and will break if the galvanzied article is subjected to flexing. No such intermetallic compound is formed when electroplating is used, contributing to better protection. One of the characteristics of zinc which makes it so useful for protecting iron alloys is its self-sacrifical tendency. If the zinc surface is broken and the underlying iron is bare, the iron will not corrode; the zinc will corrode thus protecting the iron. It will continue to protect the iron until the ratio between the area of zinc and exposed iron becomes quite large.

g. Plastics.

(1) Plastics are a wide group of materials which generally contain large organic molecules. These molecules are formed by polymerization or combination of small molecules so that plastics are often referred to as polymers. Their physical properties vary widely, depending on chemical composition and additives incorporated. The general advantages of plastics include: lightweight; high strength; simple processing and adaptability to mass production; good appearance and feel; good physical properties; and excellent chemical resistance. General disadvantages are: upper temperature limit of around 300°; hardness inferior to metals, glasses, and ceramics; dimensional stability inferior to metals, etc; and combustibility and susceptibility to ultraviolet damage. Incidental properties of plastics are good heat and electrical resistance. Specific discussion of plastics is limited to some of the more common types.

(a) Acrylics (Plexiglass) are used as substitutes for glass where we require good optical properties, impact resistance, and flexibility. They are also used as binders in paint (acrylic latex) and as textiles (Orlon).

(b) Polyester and Alkyd Resins are used in paints and surface coatings.

(c) Cellulose acetate is used in film or sheet (("acetate"), and small objects where low strength and some dimensional change can be tolerated. This material is somewhat susceptible to moisture and ultraviolet degradation.

(d) Epoxy Resins are used as adhesives, potting materials, and binders for glass fibers and other fillers. These have excellent dimensional stability and chemical resistance.

(e) Nylon is used for textiles and for objects such as gears, pipe, bristles, and substitute glassware, where high strength, abrasion and heat resistance are required.

(f) Phenolics are most often used in rigid cast objects and offer high heat resistance, dimensional stability, electrical resistance, and strength. Fillers are usually used to vary their properties.

(g) Polyflurocarbons are several types of these materials, each exhibiting varying and unique properties. For this reason it is risky to group all polyfluorocarbons together when analyzing test results. Polyfluorocarbons have high temperature resistance, excellent electrical resistance, extreme inertness to chemical attack, low moisture absorption, high strength, and a low coefficient of friction. They are used as linings, pump and valve parts, tubing, seals, bearings, gears, etc. They may be difficult to fabricate and are relatively expensive.

(h) Polyformaldehyde Resins are very strong and are used as replacements for metals in hinges, springs, gears, cams, bearings, and bushings.

(i) Polyethylene is one of the most familiar plastics and is used in sheets, films, containers, pipes and tubing, wire insulation, and glassware. They are easily formed, strong, tough, have high electrical resistance, high chemical resistance to hydrocarbons, and are tasteless and odorless.

(j) Polypropylene is similar to polyethylene, but is stiffer, less resistant to UV and more heat resistant. It is used as pipe, pump parts, hinges, electrical insulators, filament, sheet, and chemical equipment.

(k) Polystyrene is used as a low cost material for toys, refrigeration equipment, tiles, containers, and household articles. Polystyrene foam is used as insulation, flotation material, and packing material. It is also an additive for synthetic rubbers such as Buta-S and GR-S.

(l) Polyurethane is most often used as foam (foam rubber) for cushions, padding, linings, sponges, gaskets, insulation,and flotation. As an elastomer, it has good resistance to abrasion, oils, and solvents and is used for potting material, hose and cable covering, caulking, sealing, elastic fibers, paints, and laquers.

(m) Silicones are a wide range of polymers in which the main chain of the molecule is made up of silicon and oxygen. In general, they have high resistance to heat, oxidation, and weathering, water repellency, and resistance to electrical breakdown. Silicon resins are used to bond glass cloth and asbestos for high temperature applications. Silicon adhesives are resistant to moisture, weathering, and aging and adhere well to most materials. Silicone rubber and resins are used as electrical insulators, particularly under severe conditions, and as potting materials, protective coatings, sealants for buildings, dirt release coatings, foams, and molding compounds. Silicones are also extensively utilized as greases and synthetic lubricating oils. They have high temperature resistance, are inert to a variety of chemical compounds and have a low temperature coefficient. The latter properly has been exploited in the multigrade automotive lubricating oils.

(n) Urea plastics are used in utensils, adhesives, electrical fixtures, appliances, and instruments. They are odorless, have good shock resistance, strength, high heat and moisture resistance, as well as good resistance to wear.

(o) Polyvinyl Chloride (PVC) is one of the widest used plastics and may be rigid, or may be made flexible with a plasticizer. It is used for flexible tubing, wire covering, film and sheeting, fabric coating, foams, molded articles, pipe, pipe fittings, containers, tank tunings, phonograph records, floor tile, and wall coverings. It has, depending on additives, dimensional stability, abrasion resistance, good aging characteristics, toughness, corrosion resistance, and flexibility. Plasticized PVC is usually subject to fungal attack of the plasticizer.

(p) Polycarbonate is very strong and hard, and has good optical properties and, in general, excellent chemical and mechanical properties. It is used as a substitute for glass in bottles, instrument windows, etc., and for metal in housing, gears, and die cast parts.

(q) Other Vinyl Plastics include:

1. Polyvinyl acetate, which is used as an adhesive, can be used as a resin, however, this is uncommon because of its susceptibility to moisture.

2. Polyvinyl alcohol-used as an emulsifying agent and as watersoluble films and capsules.

3. Polyvinyl acetals-used as wire enamels and sheeting.

4. Polyvinylidene chloride-used as sheet material and in a variety of articles. They have high chemical resistance, are nonflammable, odorless, tasteless, nontoxic, and tough.

(2) Environmental deterioration of plastics is significant since plastics are utilized in or with most material. Their resistance to environmental conditions is highly dependent on plasticizers, inhibitors, fillers, and other additives, as well as their chemical structure. The general areas in which attack or deterioration may occur are:

(a) Moisture does not affect many plastics, except for slight absorption and the associated swelling, while others are affected greatly.

(b) Temperature limits restrict the use of most plastics. These limiting temperatures are lower for thermoplastic (remeltable) than for thermosetting (nonremeltable) plastics. The range is from 140°F. (some acylics, PVC, and cellulose acetates) to around 300°F. (polypropylene, phenolic, polyamide, and polycarbonate). At the lower temperature failure is due to flow, while at the upper temperatures chemical decomposition takes place.

(c) Chemical resistance to corrosion is present in many plastics. Resistance can be estimated and an evaluation of performance made from a knowledge of plastic chemistry. Plastics are normally resistant to solvents chemically dissimilar to themselves, and permeable to solvents chemically similar. Polyethylene, for example, a hydrocarbon, resists water and chlorinated compounds, but it swells in organic oil which is a hydrocarbon. Polyvinyl chloride resists water and hydrocarbons, but not chlorinated hydrocarbons. Additives may be affected by compounds to which the main polymer is inert. Likewise, plastics are unaffected by reactive chemicals, such as acids, bases, and oxidants, if they contain no reactive compounds. For some of the exotic applications a major concern is the composition of contaminants. Finally, temperature greatly accelerates the rate of attack and the amount of swelling, and this must be considered in applications.

(d) Ultraviolet light causes most plastics to suffer actinic damage from these rays in sunlight. This is caused by the radiation destroying the chemical bonds in the polymer molecules, which in turn decrease strength or increase the susceptibility to chemical attack. Ultraviolet damage causes discoloration, cracking, stiffening, and deformation. The range of susceptibility is from poor for cellulose nitrate, to excellent for polytetrafluoroethylene. Resistance to the ultraviolet spectra can be greatly increased by the addition of inhibitors and fillers, such as carbon black which absorbs or filters the radiation.

(e) Biological attack on most plastics prove that they are quite resistant to attack by mold and fungi. These compounds do not serve as nutrient for fungi and are not harmed by the waste products produced by the fungi. Unless fungicides are added, however, these materials can serve as inert substrates which support the growth of fungi. An exception to this are plastics containing fillers and plasticizers. These additives are frequently attacked, causing a change in the properties of the material. Polyvinyl chloride strongly resists fungi, but is frequently used with plasticizers that are attacked. The phenolic plastics (such as Bakelite) may use cotton or sawdust as filler which can and often is attacked, thus leaving a weakened porous structure. Fungicides can be added in order to prevent or reduce this. Even though the plastic is not attacked, surface growths can cause other problems to develop. Mold may hold moisture which may in turn harm other nearby materials. This moist mold may also cause electrical shorts in circuit boards or across insulators. The transparent plastics often become clouded from the combined effects of moisture, host growth, or waste products. Fungi may also be transferred to humans, food, cloth, and other materials which can cause a whole series of physiological problems.

(f) Aging refers to attack by oxygen or to slow reaction within the plastic material. Either results in embrittlement, cracking, loss of strength, etc. The effect of oxygen is similar to that of ultraviolet radiation and may act in conjunction with it. Antioxidant stabilizers are normally added to most plastics. If the plastic contains unpolymerized material this will slowly react, thus changing the physical properties; however, inhibitors, stabilizers, and controlled processing effectively prevent this.

(g) Electronic materiel presents many problems in the tropic environment.

1. In CONUS when a television technician checks a malfunctioning set, his first move is to localize the trouble. The majority of the time the insertion of a new tube, in proper circuit, corrects the problem. The philosophy of this type of maintenance is that probably the tube is bad. This type of maintenance, the product of operations

research, is not valid in the Canal Zone. Here the technician replaces the proper tube but often nothing happens, the other components may well have failed before the tubes. This difference in behavior in two different climates (the temperate and the tropical) has been known for some time. During World War II electronic equipment from the US would not function satisfactorily in the Southwest Pacific. The difficulty was attributed to fungi because in those days wiring was insulated with such natural organic products as rubber, cotton, and silk, and treated with enamels made of natural resins. The analysis was fairly sound. A solution to this problem was to spray all electronic gear with fungus-and-moisture resisting varnishes. Unfortunately not all the varnishes used performed as expected. What was gained in reliability was more than lost in maintainability, i.e., a burned out resistor or shorted capacitor could only be replaced after the varnish was removed completely and a new part installed. It was then necessary to revarnish which became difficult in the field. Between 1946 and 1951 the Naval Research Laboratory (NRL) ran a test of communication receivers near Skunk Hollow, Fort Sherman. The result of that test was the abandonment of varnishing as a tropicalizer. The new doctrine was that high grade MIL specification material was inherently able to resist the fungal attack without additional surface protection. Also, rubber, cotton, silk, etc. has been eliminated from use as insulation. This was one of those identifiable great payoffs on research. The Navy spent about $40,000 supporting the test and began saving $5 million a year after it was finished. This then became the rationale in 1951, viz., use the best obtainable components in electronic gear and tropical effects will be minimized. The U.S. Army, between 1955 and 1959, tested electronic components in the Canal Zone and the policy was shown to still be appropriate. Low quality items were quickly attacked by the environment as expected, however, surprisingly, some high quality, expensive items also failed. For example, glass-encapsulated capacitors, made by a reputable glass company, guaranteed against "everything," failed rapidly. This failure was caused by corrosion products in the area where the leads come through the glass which swelled enough to break the envelope. The glass company still guaranteed their capacitors, of course, but they hadn't tested them here. After 1959 the doctrine of high quality, as a solution to the tropic environmental problem, began to be suspect. What caused this change is not known, but it is hypothesized that the chamber environmentalists took over and that new and allegedly superior plastics, etc., were being used without any field testing to back up the chamber tests.

2. Early in the Tropic Test Center's history, it was observed that electronic items failed more quickly in storage or when quiescent than when operating. Accordingly, test plans have been written to include several months in storage for some items with occasional brief exercising, in addition to continual use of other test items. This is still good philosophy in that it assists in differentiating between wearout and environmental degradation, by producing both. Since 1965 the Center has conducted a test of advanced electronic components for TECOM.

The items were tested at two sit` seashore and jungle, and in two modes, energized and unenergi- .. ·K printed circuit boards were tested concurrently with the ests of omponents, capacitors, resistors, chokes, coaxial e nnectors, ables, and cable connectors. These circuit boards did not last long c the seashore site regardless of whether or not they were energ' .ed. Their useful life was longer in the jungle, but no s ' ntly. Some of the cables were insulated with a polyuretha e compound which became brittle and came apart after three months exposure to sunlight. Telephone cable connectors corroded so badly in three weeks that they could not be disassembled. Silver plated coaxial connectors corroded quickly. Adjustable ceramic capacitors with silver plates failed under load due to migration of silver ions into and through the porous ceramic. Disc ceramics capacitors out-performed tubular capacitors by two orders of magnitude. Paper dielectric capacitors, no matter how encapsulated, failed quickly. Silver mica capacitors encapsulated in high quality plastic did not fail during the 5 years of the test. From some points of view solid state circuits and integrated circuits (IC) seem to solve many of the problems of electronic reliability in the tropics. However some investigators are concerned about heat dissipation from such small volume equipment as solid state devices, and feel that while the amount of heat dissipated is low, the amount dissipated per unit of area will be large enough to cause failure.

i. Optics and ceramics require special fabrication and implementation.

(1) Glass used in lenses and other optical elements is relatively soft and therefore more easily damaged than conventional glass. While no instance is known where fungi have directly attacked such material, the organisms have caused extensive damage to all types of optical equipment. Until the advent of air conditioning it was not unusual in the Canal Zone to send microscopes back to the factory for repolishing of the lenses every few years. Now that is not necessary. The mechanism of fungal attack on optical equipment seems to be that minute amounts of organic debris, such as oil from one's fingers, insect droppings, and bacteria lodge on the glass surface and serve as a source of nutrient for the fungi. The fungi colony secretes waste products which etch the surface of the optical element, thus degrading its performance . Lenses have been so severely damaged that small grooves were present on the surface. Multielement lenses are frequently cemented together with Canadian Balsam, a natural gum which is very vulnerable to fungal attack. The cement becomes invaded by the fungi which in turn destroys the optical properties. Cuprate cements have been developed to prevent this Attempts have been made to defeat fungi in optical systems by incorporating dessicants, volatile fungicides, and radioactive materials in the instruments. Results are disappointing and none have proved practicable. Some lost their potency quickly, others corroded the metallic parts. While effective, the radioactive substances present a health hazard.

(2) Fungal damage to or on ceramics also occurs. An example of this has been observed at the Navy's Summit Radio Station. There are thousands of ceramic insulators located there and some are used as spacers in antenna feed lines, others are used to break guy wires with non-resonant sections. During the dry season the relatively strong trade winds carry dust containing minerals and other substances which serve as food for fungi and other microorganisms. These substances are deposited on the ceramic insulators. The fungi survive but do not flourish and the station functions normally. The change in the environment with arrival of the rainy season allows the fungi to begin to flourish. As they grow the colonies spread until the entire surface of the insulator is covered. Their hyphae and metabolic products together with the humidity turn the insulator into a resistor. This results in much of the station's power being shorted out thus greatly reducing the radiated energy. The only remedy to the problem is to clean each insulator during the dry season. Microscopic examination showed no damage to the ceramic insulators, therefore this process restores the station's efficiency. Laboratory investigation showed that contaminated insulators, when they are dry, have an end-to-end resistance of infinity, but after being put in a refrigerator for an hour and then removed they had resistance of less than 100,000 ohms. Cleaned insulators, on the other hand, had resistances in the megohm range after being taken from the refrigerator. This is a good example of where no damage was caused by the fungi but the performance of the equipment was seriously degraded due to its presence. This phenomenon is not as likely in portable equipment, however fungi presence should be suspected when the transmission range is suddenly reduced. Examination should be made of places where fungi could grow and act as shorts or bypasses.

j. Protective coatings include various types of paint.

(1) Paints consist of a drying oil vehicle such as linseed, fish, or tung oil into which a pigment and/or dye has been incorporated to give the desired characteristics. It is important to understand that drying oils do not dry by evaporation, but that the drying process is a chemical reaction in which the oil combines with oxygen to form a kind of plastic. Ordinarily, the reaction takes place very slowly, so that dryers (usually manganese or cobalt compounds) are added to hasten the process. The protective properties of paints are reduced by UV radiation, moisture, weathering (the combined or single effects of alternate heating and cooling), abrasion, poor application, and by organisms such as fungi and algae. Modern paints contain chlorinated derivatives of isoprene and perform very well in the humid tropics. Although, paints are usually made up of drying oils (plus pigments and perhaps a volatile thinner) to adjust viscosity today, natural and synthetic gums (or plastic-like materials) are added to or may even replace the traditional drying oils. These natural gums and many synthetic ones are food for fungi which consume the gums and thus destroy the coatings. Signs of failure in a coating include: corrosion of the substrate (if metal); chalking

(powdery film on a surface); alligatoring (areas of paint shrink away from neighboring areas yielding a surface that looks like an alligator skin); and erosion (wearing away of the coating).

(2) Attack by fungi and algae in temperate zones has been recorded, but nowhere are these organisms as virulent as in the humid tropics which provide almost an optimum environment for their growth. The seasonal cycling, wet and dry season, is believed to accelerate the biotic degradation of materials. The mechanism of biotic attack is the consumption of the natural drying oils in paint by the microorganisms. Even in cases where the ingredients of a paint, varnish, or lacquer are impervious to biotic attack, the composite product may be highly susceptible to degradation due to the addition of plasticizers and extenders which were added during manufacture. Certain pigments, such as zinc oxide, are used to suppress fungal attack. Others which have similar properties cannot be used because of toxicity to humans or lack of durability, but we accept short life in trade for their desirable higher toxic properties. Most protective coatings which have inherent ability to withstand biotic attack dry to form hard, impermeable surfaces

k. Shellacs, lacquers, varnishes and enamels also provide protective coatings.

(1) Shellacs and lacquers, which are gums dissolved in a volatile solvent (often lacquers have pigments added), have no drying oil, therefore form hard, impermeable surfaces very quickly and as a class are less vulnerable to biotic attack than the classical paints. However, the use of solubilizers of plasticizers can change this characteristic drastically. Varnishes are considered to be gums, natural or synthetic, dissolved in a drying oil, and the product is expected to have characteristics contributed by both constituents. Some are very susceptible to attack while others, based on tung oil, have great natural resistance. Enamels are similar to varnishes with the exceptions that they have coloring pigments added, and the cured coating possesses a higher degree of gloss. Although in the early part of the 20th Century the term "enamel" was used to describe only ceramic type coatings, today, the term has been extended by common usage to include those resin based coatings prepared by a two-step process which includes solvent evaporation, followed by a chemical reaction to cure or set the enamel coating.

(2) The porcelain enamels, which are inorganic glass coatings, are impervious to biodetermination although they can act as a support medium. The organic-based enamels may be readily attacked by microorgnisms.

l. Protective coatings can also include:

(1) Two preservative oils tested at USATTC during 1968-1969.

One was Oil Preservative, VV-L-800, and the other was Oil Preservative, MIL-L-21260. These were tested in the jungle for a year and both effectively prevented corrosion on immersed portions of steel specimens. However, the VV-L-800 oil emulsified and the oil was attacked by organisms at the interface between the oil and condensed water which was formed in the container. Another product for preventing corrosion which is available through Army channels, operates as a protective vapor. Blotting paper is soaked in liquid and then put in a tool chest or container where the volatile vapors are confined. Such compounds are very successful and leave no greasy or oily coating on the metal. While no evaluation has been made of the Army product at this Center, it has been noted that a single application of an unidentified commercial product has kept tools, stored in a chest, corrosion free for over 14 years and is still functioning satisfactorily. This particular product has the disadvantage of softening the paint and varnish on tools, however, it did not attack the painted surfaces of the chest itself.

(2) A common method used to protect machinery from corrosion is to inclose it and to add dessicants. The idea sounds attractive but is not universally effective. The envelope is usually of some plastic film, protected by an exterior wooden case. Often the envelope is punctured by nails when the wooden case is put together and moisture then enters and corrosion begins. The dessicant is effective in absorbing moisture for a time but it eventually loses its ability to do so. Changes in temperature within the envelope, from night to day, causes breathing which brings a constant flow of moist air into contact with the protected article. It has not been uncommon to find several inches of water in such containers due to this breathing effect. In addition, plastic films are permeable to water vapor even though they are impervious to free moisture, i.e., waterproof. This means that water in the vapor or gaseous state will pass through them although the liquid will be kept out. Numerous errors in packaging corrodible items have been observed because this fact is not understood. Cellophane and polyethylene film, both of which are popular for wrapping items, are both waterproof but not vaporproof.

m. The life of protective coatings can be extended in locales of high relative humidity. The use of air conditioning to cool interiors reduces the exterior wall temperature to below the dew point, thereby causing a fairly constant film of moisture to form on the exterior painted surface. This condition is conducive to rapid fungal attack, and fungal staining of the exteriors of air-conditioned buildings is common. This is especially true if the surface is shaded from sunlight and the insulating qualities of the structure are low. One method to control or prevent this growth is to incorporate various toxic substances in the protective coating. Some of the synthetic marine varnishes have filtering pigments added which effectively increases their resistance to ultraviolet radiation, thus increasing their useful life.

n. Reduction of degradation.

(1) When zinc plating or galvanizing is not appropriate, organic protective coatings, such as "paints," on the surface can be used. These are relatively cheap, easily applied, and sometimes long lasting. By proper choice of pigments an enhanced protective effect can be obtained. On the other hand, the wrong choice of either pigments or some other component can cause accelerated corrosion once the paint film is broken. Where paints are not the answer to problems in preventing corrosion, the so-called "surface conversion methods" can be used. An example of this process which is familiar to Army personnel is the bluing on firearms and bayonets. Most of these processes make use of a weak solution of phosphoric acid to produce iron phosphate, which is then converted to some other compound by further treatment. Iron phosphate makes an excellent surface for holding paint, and being a corrosion product inhibits further corrosion. Good modern painting practice therefore requires the use of phosphoric acid wash primers when painting ferrous surfaces.

(2) Degradation included in most of the foregoing data deals with corrosion attack on metals, as caused by oxygen. While this is the most common and most expensive type of corrosion, other elements such as the halogens (chlorine and its relatives) and other chemicals also cause corrosion. Usually the mechanisms are the same as those described, and the same protective measures will work. Certain plastics decompose and release corrosive gases which attack neighboring metals. As an example, this kind of reaction goes on within electronic gear in which plastics displaying this behavior are used as insulation and the metals in solder are susceptible to attack by the released gases. The corrosion of equipment may continue even when an attempt is being made to prevent that corrosion. It has already been pointed out that some paints, used to prevent corrosion, actually make matters worse when the paint film is broken. Lubricants and especially greases are often smeared on metal objects to prevent corrosion and usually the process is effective. However, the grease must be chosen with care. If the grease contains graphite, the results will be unsatisfactory because graphite is carbon, and carbon in the presence of moisture of any electrolyte will cause rapid corrosion of all the metals commonly used in military equipment

7. Human Factors Engineering Evaluation During Environmental Testing.

a. Tropic Testing Problems

(1) Overview. Environmental extremes will have a significant effect on the overall performance of man-materiel systems. It is imperative then, that Army equipment be subjected to rigorous tropic testing testing. The problems associated with this mission require special emphasis. A commercial text, authored by D.A. Dobbins, titled "Toward Some Solutions to Tropic Testing Problems" is an excellent source document on this subject and is presented here. There are many military operational problems that are unique to or enhanced by the tropical environment.

(a) A very critical problem to combat operations is target acquisition. Dense tropical vegetation offers an excellent sanctuary from air-to-ground and ground-to-ground observations.

(b) Communications are degraded. Jungle and topography combine to degrade the propogation of electromagnetic and acoustic energy.

(c) Heavy rainfall, vegetation, steep slopes, slippery and weak soils all contribute to greatly reduced vehicular and foot mobility.

(d) The humidity cycle fluctuates from very high levels to complete saturation. When coupled with intense solar radiation and the high level of microorganismic activity, rapid deterioration and malfunctions are caused in many types of materiel items and their component parts.

(e) High temperatures and high humidities make it difficult for people to dissipate body heat by perspiration, which lessens the physical ability of ground troops to move quickly or carry heavy loads for long distances. Troop health is impaired when units must stay in the field for long periods of time.

(2) The dense jungle canopy influences any item that must penetrate it. Problems in deliverability and effectiveness are encountered with artillery fire, bombs, and airdrops of all kinds. From below the canopy, dispersion and rise of signalling smokes and agents present problems because of the stagnant, slow moving air mass trapped there.

b. Tropic Test Period. Tropic Test Center recommends a minimum 12-month test period. We are quite certain that this period overtests some materiel and undertests others. However, in the absence of definitive information, the recommendation is based on one full cycle of exposure to wet and dry seasons with associated changes in rainfall, heat stress, sunlight, soil conditions and microbial growth. The reason for the seemingly lengthy test period is to allow environmental degradation to surface. In the humid tropics the major causes of degradation are:

(1) Degradation from microorganisms occurs because high humidity and even temoeratures favor their growth. Biotic attack is most severe under the jungle canopy.

(2) Actinic degradation (from sunlight) occurs because the ultraviolet rays change the molecular structure of exposed materials. Degradation from sunlight is most severe in open sites, but occurs in the tropics under full cloud cover.

(3) Degradation from heat stress occurs from high temperatures; its effects are most severe during the dry season and in open sites.

(4) Corrosion of metals occurs at an accelerated pace in the tropics, particularly at coastal sites. This is due to relatively high salt concentrations coupled with daily flucturations of surface humidity from saturated to a dry state.

(5) Microbial degradation increases with the length of the test. Different organisms have different incubation periods which are not well known. For microbial attack to occur, there must be micro-organisms ready for reproduction, a nutrient media, and suitable weather conditions. Testing for microbial deterioration should be scheduled, at a minimum, from April through December.

(6) Actinic degradation is active almost all year in the Canal Zone. Ultraviolet rays penetrate the cloud cover in sufficient quantity to produce degradation of susceptible materials in periods ranging from a few weeks to a few months.

c. Testing for heat stress is most effective March through May and least effective in the rainiest months of October and November. Consequently, to realistically assess the range of the major cuases of degradation requires a full dry season of four months (December-April) and extension into the heaviest rain months (October-November). Environmental data base investigations showed that the numbers of fungi and bacteria in the air that are deposited on surfaces vary radically

from month to month, hour to hour and place to place. Microbial inspections continuously carried out on various test items exposed to the environment show that during the course of a year, several species of microorganisms will be dominant for a period only to be succeeded by different species at other intervals. Some species degrade materials, others do not. These two sources of information indicate that there is no single predictable pattern for microbial depostion and growth. The pattern is best described as chaotic. However, the information also indicates that any short test period may yield inaccurate predictions of the results of longer exposure intervals.

(1) It has been observed that metals placed on test in the natural environment suffer little attack at first, later the rate of attack rises slowly, then rapidly and still later the attack slows down. These observations also apply to paint, textiles and electronic components. This hypothesized decay function has not been quantified of verified and undoubtedly varies with the type of material. The observation suggests that one should expose materials long enough to allow the decay curve to stabilize. A USATTC methodology investigation is studying the decay curve for several types of material.

(2) The Test Design Problem. Test design problems are related to the preceeding two problems. There is no design that can compensate for insufficient sample size and test time. However, given sufficient items and time, there are many different ways to improve test validity by proper design. There are many kinds of test variables in the tropics that can influence materiel performance. There are variations in microclimate, types of vegetation and soils. There are differences in modes of materiel storage such as; open, covered, jungle, dehumidified and air conditioned, and so forth. There are also differences in military operational deployment such as fixed vs., mobile, day vs., night, long range vs., short range, etc. If test could be designed so that exposures represented separate and independent samples that covered the full spectrum of micro-environments, storage and surveillance modes, and significant military deployment modes, then USATTC would be well on its way to the goal of valid tropic testing.

c. Specific HFE Evaluation Measures

(1) Vehicles, Vans and Shelters are evaluated and measurements of the following parameters are essential: Temperature buildup in compartments where personnel will be confined; noise levels; airflow rates; humidity; illumination; and noxious gases. Measurements of internal compartment atmosphere, humidity and temperature should be

made with doors, windows or hatches both closed and open and with the full crew complement since personnel as well as equipment contribute heavily to the internal compartment conditions. For portable items, setup and take down times should be recorded. Since the warm, humid tropic environment often creates a considerable amount of vapor on windows and optics, the defogging systems of the test item should be evaluated including measurements of time to defog for systems with critical mission reaction times.

(2) Communications/Electronic Equipment are evaluated and in the case of voice communication equipment, speech intelligibility tests should be conducted during the range testing phases in the various tropical environments (open grass lands, jungle areas,etc.) since the behavior of radio waves and sound can be affected significantly by jungle vegetation. In the testing of optical devices (e.g., night vision aids) and auditory devices, standardized procedures for operational test methodology have been developed. Such techniques permit objective data to be obtained on the detection capabilities of these devices when used in the tropics and comparison with normal/unaided jungle vision and hearing should be made.

(3) Weapon systems are evaluated and an important consideration for inclusion in HFE evaluations of these systems is to determine what effect temperature and humidity have on operator performance. Quantitative data on firing accuracy, operator error, system reaction time and maintainability should be recorded under operational conditions extending over a period of hours, and under the various tropical environments.

(4) Clothing and personal equipment are evaluated and parameters which are essential to a human factors evaluation of these items include: comfort; fit; ruggedness; protection; adequacy of ventilation; ability to absorb and release moisture and perspiration; ease of donning and doffing: compatibility with other equipment; and user acceptance. Performance tests of these items must include operations with the test item under realistic conditions of dress and equipment used in actual operations. For head gear, degradation of vision and hearing should be measured against acceptable standards.

(5) In addition to the aspects listed above, for man-packed equipment, such factors as overall weight and its distribution, carrying mode (back, shoulder, etc.), adequacy of support systems, and ease of donning and doffing must be evaluated. Goggles and protective masks should be tested under conditions of high humidity to determine if vapor accumulation on glass or plastic surfaces degrades user performance

below acceptable levels. Tropical sleeping gear should be tested for heat buildup, adequacy of ventilation, comfort, ruggedness, protection, ease of entry and exit, and survival value. Qualitative data regarding such factors as fit and user acceptance of personal equipment is acquired through proper administration of questionnaires and interviews and through observations made during the testing cycle.

(6) Simulated combat measures involve activities when the service test calls for some index of joint man-materiel performance in combat, it is desirable to score objectively certain elements of simulated tactical operations. The usual scenario calls for patrol, dig-in, defense, ambush, attack and other mission critical subtasks. Time measures can be made for those subtasks requiring movement from one location to another, input of specific operator data and other critical mission reaction times. Number of targets detections and accuracy scores can be used with attack and defense subtasks. Number and frequency of critical operator errors should be recorded for evaluation of mission essential task performance.

(7) When there is information to be gained from knowing the performance decrements due to the environment, the following methods may be used. Test subjects are administered one or all of a series of mental and physical tests. Examples include:

(a) Reaction time

(b) Strength

(c) Psychomotor (eye-hand-foot coordination)

(d) Sensation and perception (visual, auditory acuity)

(e) Physiological (heart rate, body temperature)

(f) Intellectual (problem learning, solving)

Subjects are then given a "real-life" task such as a simulated tactical operation. Following this task, the subjects are measured using identical or parallel mental and physical tests. The differences in average scores before and after constitute an index of the human "cost" of man-materiel performance in the tropics. A good design is to have a "control" group who receive all the before and after tests, but do not participate in the simulated tactical operation.

8. Sound and Visibility in the Jungle.

a. Sound behaves differently in the jungle than in open areas, primarily because of the mass of vegetation. Human auditory responses are also influenced by the mass of vegetation. The Tropic Test Center has conducted a series of physical transmissions horizontally along jungle paths. Pure tones, ranging from 63 to 8000 hertz (Hz) were generated and measured at progressively increasing distances from the sound source. The following major results were obtained:

(1) The jungle acts as a low-pass filter to audible sound. Lower frequencies pass relatively unaffected, while higher frequencies are effectively screened. For example, the 63-Hz signal lost 41 decibels (db) through 400 feet of jungle and 39 db over open terrain. The 8000-Hz signal lost 86 db through 400 feet of jungle and 52 db over open terrain.

(2) Day and night thermal conditions vary under the jungle canopy. At night there are inversions, i.e., with increased elevation the air warms rather than cool. While this inversion could possibly cause refraction of sound at night, there were no significant differences between the received strength of day and night transmissions.

(3) Total horizontal signal loss through the jungle varies exponentially. Therefore, linear equations such as "decibels per foot" cannot be used in extrapolating transmission losses beyond known ranges.

(4) Ambient jungle sounds have also been studied. The total (all-pass) sound pressure levels average 60 db through the 125 to 8000-Hz frequency range. Moderately high noise levels are found from 63 to 125-Hz (wind rustle, dripping water, etc); low noise levels are found from 250 to 1000-Hz. Noise levels increase rapidly from 1000 to 8000 Hz predominantly due to insect noises. At night, the insect noise increases with a drop in the lower frequencies.

b. Jungle listeners were included in a separate study and the function performed by soldiers in a combat MOS. They were stationed along the same transmission paths and exposed to the same signals as mentioned above. Frequency and intensities were recorded when the sounds first became audible to the listeners. The following conclusions were made:

(1) The point of maximum auditory detectability shifts to the lower frequencies as the listener moves farther from the sound source. This is caused by the masking of jungle noises and the difference in transmission loss for different frequencies. For example: with the source signal constant, maximum detectability shifted from 4000-Hz to 1000-Hz at 400 feet, beyond 400 feet the most detectable frequency shifted to 63-Hz.

(2) Signals from 63 to 1000-Hz were most audible at night because the insect noises, in the higher frequencies, did not mask the signals. Conversely, signals above 1000-Hz were more audible during the day because of relatively low insect noise.

(3) The human auditory thresholds in the jungle can be predicted when the prevailing ambient noise levels and signal transmission loss are known.

(4) Frequently, listeners can hear signals that are not measurable. This occurs because the human ear has a more efficient filter to screen out unwanted signals.

(5) The most audible frequency for signaling in the jungle is 1000-Hz provided that sufficient source acoustic power is available. When power is limited and signals must be heard over a long distance, a 63-Hz signal should be used. If signals must be heard over short distances (200 to 400 feet), but not beyond, the 4000 to 8000-Hz signal range should be used.

(6) With complex noises, such as combustion engines and human voices, the lower frequency components determine the level of audibility. The jungle systematically screens out the higher frequency components as the distance is increased from the source.

c. Another study probed the ability of jungle listeners to judge the direction of sound when the target location is unknown. Three types of sounds were transmitted through thick jungle to personnel. Sounds transmitted were: Pure Tones - 65 to 6000-Hz; continuous operational noises - walking patrol, moving personnel carrier, human voices, folding and ribbon saws, and a paddled boat; operational impact noises - machete, M14 rifle, and an 81mm mortar. These sounds were transmitted to reach the listeners head at eight different angles: Front of hear - 0°; back of head - 180°; right ear - 90°; left ear - 270° and the four oblique angles between each of the preceding points. The listeners judged the direction of sound by pointed arrows attached to an azimuth table. The listeners performance was measured by angular error (in degrees) between the judged direction and true direction. Thus the angular error could range from 0° (no error) to 180° (maximum error). "Reversal" errors are defined as those between 91° and 180° (i.e., listener was more wrong than right). The following results were obtained:

(1) Localization of sound direction was poor in the jungle. Average errors were 30° for pure tones, 29° for continuous operational noises, and 23° for operational impact noises. Studies conducted over open terrain resulted in much smaller errors. Sound localization in the jungle is difficult because of the complicated geometry of the vegetation. First, the vegetation scatters sound such that the listener receives a distorted and attenuated input. Secondly, sounds reverberate causing echoes.

(2) For pure tones, errors were greater for the higher frequencies. The errors become more pronounced when the distance between the source and listener was increased.

(3) Ten percent of all responses were "reversals." Reversals were highest for pure tones - double that of continuous noises and triple that of impact noises. Reversals increased significantly as the distance between the listener and source was increased. Regular localizing errors did not increase significantly with distance. Two sounds that were particularly susceptible to being reversed were human voices and noises associated with walking patrols.

(4) The angle between the sound source and the listener's head position had a significant effect on the localization error. Sounds were best localized (approximately 19° error) when they came to the right-left axis (directly into the ears). Larger errors (approximately 31° error) were made when the sound came toward the listener's face. The largest errors occurred (approximately 46° error) when the sound came from behind the listener's head. The pattern was consistent for all sounds. It should be noted that with a recurring sound, a listener could rotate his head until he thinks the sound is coming from his direct left or right. By doing this, he would increase his accuracy by 65 percent for frontal and 145 percent for rear. This head rotation technique must be taught to listeners, because the natural reaction is to turn the eyes toward the sound.

(5) Other effects in sound localizing were noted. For example, when the sound came at an oblique angle to the listener's head, whether front or back, there was a tendency to judge the sound as coming directly into the ear at a right angle. When the sound actually came to the right-left axis of the head, listeners judged it as coming from in front of the ear more frequently than from behind the ear.

d. A supplemental study was conducted to determine if different types of headgear affect a listener's ability to judge target localization. An experimental helmet (Hayes-Stuart) was included as part of the study. Listeners also wore standard helmets and soft caps, as well as no headgear. Pure tones (125 and 2000-Hz), a continuous noise (voices) and an impact noise (machete chopping underbrush) were transmitted to 32 listeners. The overall experimental design was similar to the first localization study described in preceding paragraphs. The following conclusions were drawn:

(1) Headgear did not degrade human capability to judge sound direction in the jungle. Localization errors were approximately the same for all three headgear conditions and for the bareheaded condition.

(2) Data on types of sound, direction angle and reversal errors closely approximate those data obtained in the first localization study.

e. Acoustic sensor. Studies were made to determine the capability of these devices to detect human voices. The sensors were placed at varying elevations in the jungle. As previously discusses, naturally occurring jungle ambient noise levels are unevenly distributed over the frequency spectrum, i.e., moderately high at lower frequencies and very high at higher frequencies. Fortunately, the jungle is relatively quiet in the frequency range of the human voice. Therefore, if an acoustic filter screened out the lower and higher frequencies it might increase the detection of human voices. A study was designed to test this assumption.

(1) Human voices were recorded and then transmitted at slant ranges (600, 900, and 1200 feet) to a tower on which microphones were placed at 5, 20, 60 (mid-canopy), and 100 feet (above canopy). Two reception systems were used to record transmitted voices, one filtered and the other unfiltered. The recordings were played back through headsets to an experienced group of listeners (Army Security Agency voice or Morse Code monitors) and an inexperienced group of listeners (combat MOS). The major results were as follows:

(a) Filtering results in a significant increase in detections. Detection percentages were 68 percent for filtered sounds and 50 percent for unfiltered sounds. Filtering superiority was consistent for all elevations, distances, nigh and day, and experience level of listeners.

(b) At greater distances, filtering became increasingly significant. For example, at 1200 feet 51 percent of the filtered sounds were detected while 28 percent of the unfiltered sounds were detected. This result implies earlier detection if in an operational setting.

(c) A major disadvantage of the filter is that jungle ambient noises, without voices mixed in, sounded like voices and a greater number of false detections (i.e., jungle sounds thought to be voices) were made. In an operational setting this could be overcome by allowing the listener to alternate between filtered and unfiltered modes.

(d) Filtering was more effective at night than during the day. This difference is probably explained by the higher level of night ambient noises, even within the unfiltered segment of the filtered signals.

(e) Recordings made of sounds above canopy (100 feet) were more easily detected than those at lower elevations. Detections were lowest for the recordings made at the 5-foot elevation. The probable reason for this is that the slant angle between source and microphone is most acute (smallest) at the 100-foot elevation, thus the sound passes through less foliage and consequently is less scattered. This study was conducted in the wet season, therefore this effect may not be the same during the dry season when the wind increases above the canopy.

(f) Experienced listeners were 8 percent more accurate, in detections, than inexperienced listeners.

f. Visibility in the jungle involved a series of studies to evaluate the capability of personnel to detect targets in the jungle, without the use of optical aids, were conducted by this Center.

(1) Methods included target radii (5 or 6) which were established in jungle areas separated at 30° intervals across a search span of 180°. On each radius, 6 to 10 distances were marked. The observers, enlisted men in a combat MOS, were stationed at the midpoint of the semicircle. Targets appeared randomly - from one radius to another, and from one distance to another. Both correct and incorrect target detections were recorded. Three primary measurements were made:

(a) Limits of visibility - distance at which percent detection reached zero.

(b) 50 percent thresholds - distance at which 50 percent of the targets were detected.

(c) Gradients of visibility - shape of the detection curve from the nearest to the farthest distance.

(2) Human targets in a standing position were positioned in the jungle foliage. When searching for standing motionless men observers most frequently spot the vertical lines of the trunk and legs. The next most frequently spotted were the head, face, and shoulders. The third most frequently spotted was the dullness of the standard fatigue uniform. The relative symmetry of the body contrasts with the chaotic appearance of the jungle vegetation. This suggests that jungle camouflage should emphasize better obscuration of head-shoulder regions, reduction in size of individual pattern elements and increase brightness of some pattern elements. However, the four-color camouflage (1948 pattern) resulted in a 16.4 foot average reduction in threshold, a 12 percent reduction in total detections when compared with the standard fatigue uniform.

(a) Observers, on the average, required from 25 to 45 seconds to detect a standing human target.

(b) Colored lenses, designed to enhance background contrast and apparent brightness, did not improve target detections in the jungle. In the darker moist evergreen forest, yellow lenses significantly degraded target detection and reduced depth perception. In the lighter conditions of the semievergreen forest, yellow red, and dichroic lenses neither helped nor hindered target detection. However, difficulties were encountered from condensation on the inside of lenses - both spectacles and goggles.

(c) When comparing visibility of semideciduous forests with most evergreen forests, it was found that horizontal visibility is generally higher in the evergreen forest. In the moist evergreen forest (both wet and dry seasons), 50 percent detection thresholds generally range from 70 to 75 feet; visibility limits range from 100 to 110 feet and the visibility gradients are "S" shaped. In either type of forest, the observer's visibility is limited to an envelope of 110 to 120 feet. One hundred percent target detectability usually ends between 20 to 30 feet.

(d) The moist evergreen forest retains a gloomy aspect throughout the year when under the canopy. Horizontal luminance levels range from 5 to 15 foot candles during the wet season and 20 to 35 foot candles during the dry season. The semideciduous forest is much brighter than the evergreen. Luminance levels range from 30 to 60 foot candles during the wet season and 125 to 200 foot candles during the dry season. Illumination levels have little or no effect on horizontal target detection. The potential importance of illumination is neutralized by the effect of obscurative eye-level vegetation.

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APPENDIX A

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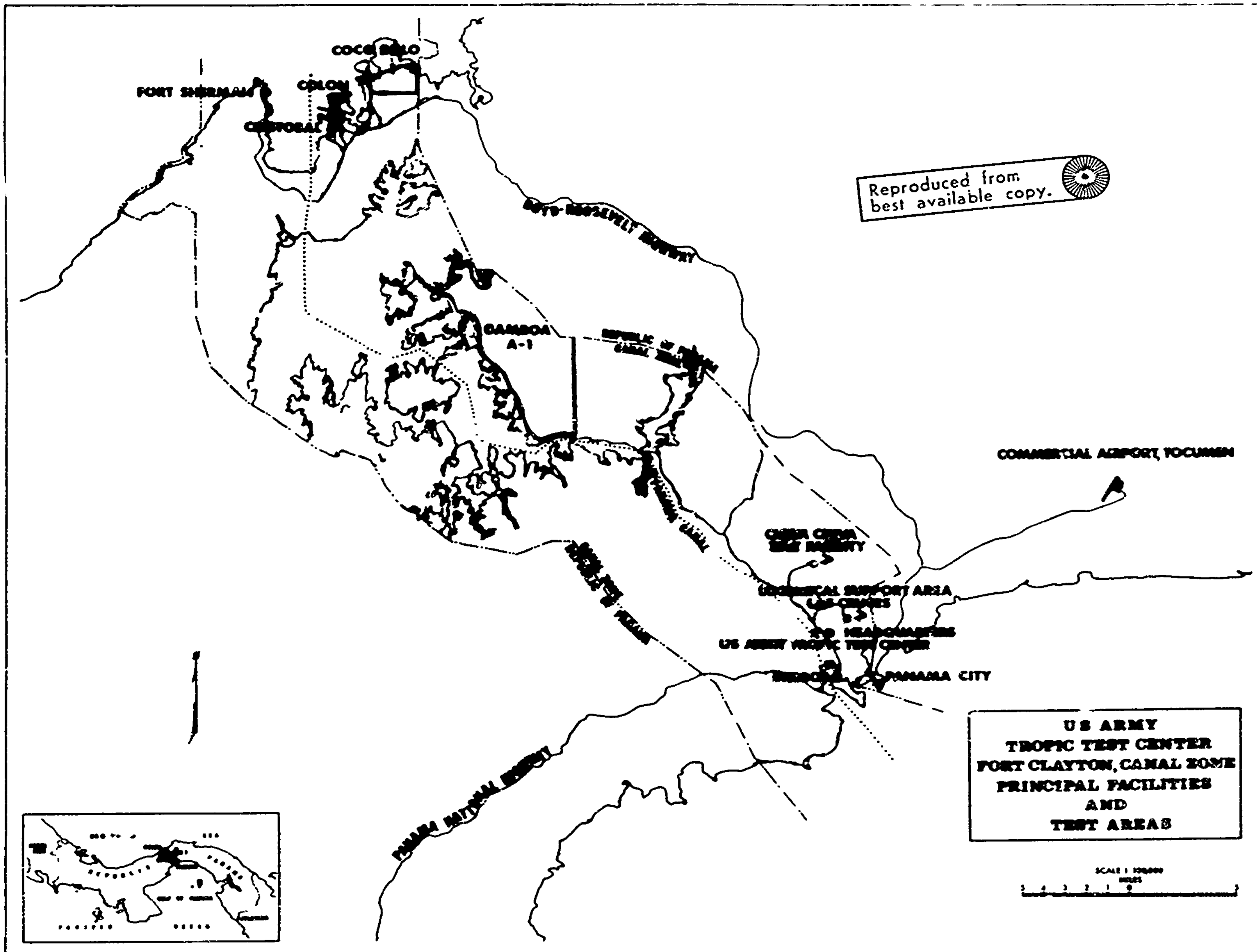
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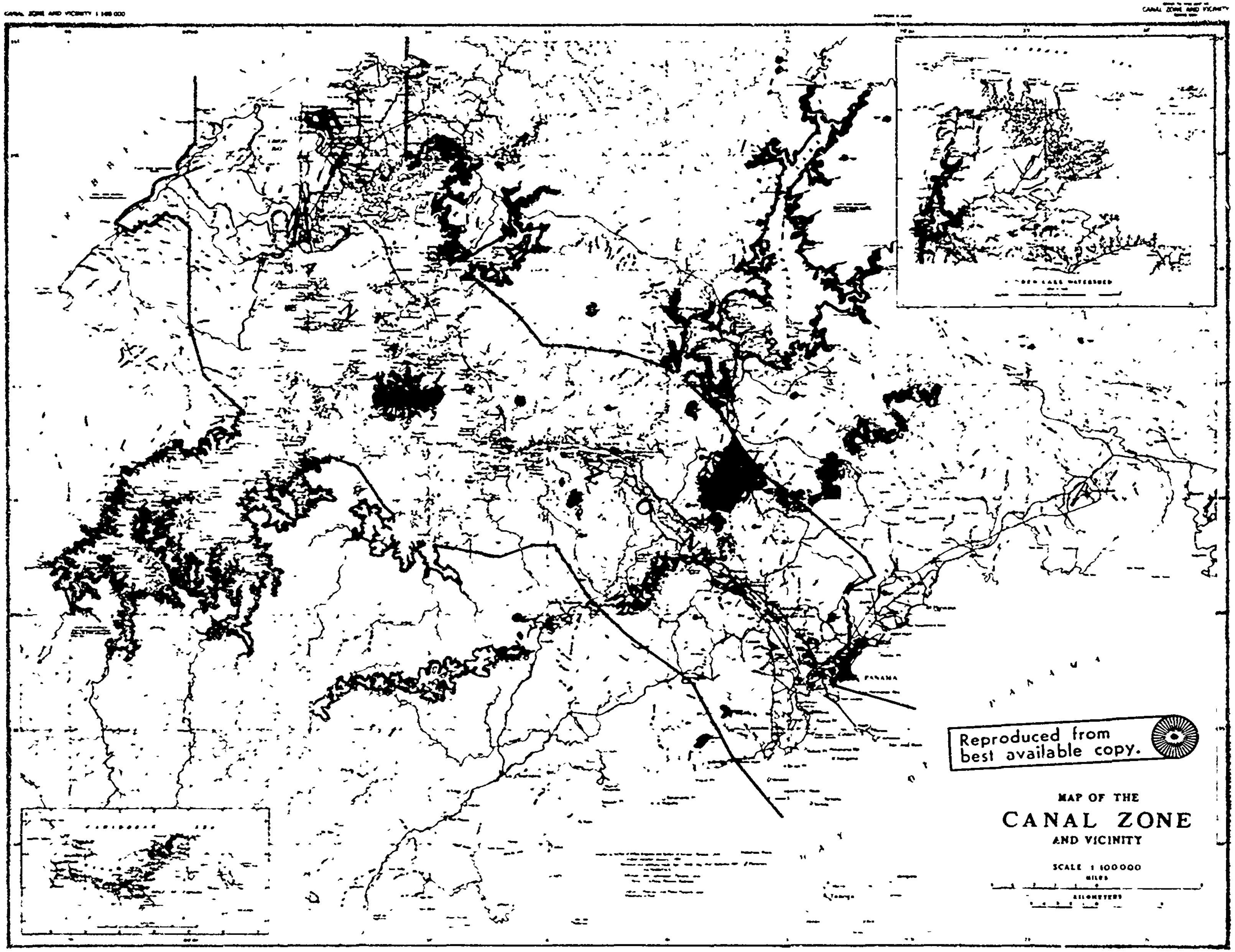
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